Ontario
Ministry of
Transportation and
Communications

REPORT EM-58

PROCESS CONTROL PILOT STUDIES ON GRANULAR 'A' GRADATION BY THREE COMMERCIAL PRODUCERS

Engineering
Materials
Office

PROCESS CONTROL PILOT STUDIES ON GRANULAR A GRADATION BY THREE COMMERCIAL PRODUCERS

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INTRODUCTION

Report EM-46, entitled "Aggregate Producers' Process Control of Aggregate Gradation" was published in April 1981. One of the approved recommendations of the report was to implement some pilot studies during the 1981 construction season. Many aggregate producers expressed interest in experimenting with the proposed process control system by sampling and testing the produced aggregates in their own plant using their own testing technician and laboratory, and following the Ministry's guidelines or special provisions.

The proposal for the pilot projects required that sampling and testing of aggregate gradation be done by the producer on the contractor's behalf and that a full acceptance testing program be carried out by M.T.C. contract personnel. In the report it was further indicated that the pilot study test results would be statistically analyzed by the Engineering Materials Office, and the entire system evaluated, de-bugged and refined. It was envisaged that, by carrying out such projects, both the industrial sector as well as M.T.C. would gain valuable experience and insight towards the eventual adoption of the process control system on a Provincial basis.

During the 1981 construction season three commercial aggregate producers volunteered to sample and test granular A aggregates supplied to M.T.C. contracts utilizing their own personnel in their plant laboratories. The three aggregate producers were: Harnden and King Construction Ltd., Genstar Stone Products Inc.-Nelson Quarry and Walker Industries-Vineland Quarry.

The producers' sampling and testing programs, including random samples, minimum frequencies, sampling methods and laboratory testing techniques, were set by the Engineering Materials Office in Downsview and were closely followed by the participating agencies. Presented in this report are the descriptions of the three process control sampling and testing programs together

with the analysis and evaluation of the test results. Comparisons of the producers' and the Ministry's test results are made using statistical probabilities.

While the programs carried out by Harnden and King and Genstar Inc. were released previously as Material Information Report number 35 and 35A, they are re-issued here for the sake of completeness and overall evaluation.

Report No. 1 81 09 18

PROCESS CONTROL PILOT STUDY ON GRANULAR A GRADATION BY HARNDEN & KING CONSTRUCTION LIMITED

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1. Introduction

This report contains the description, analysis and evaluation of one of the completed pilot studies carried out by Harnden & King Construction Limited of Cobourg, Ontario.

2. Description of the Project

Harnden & King Construction Limited was the successful bidder on Contract 81-18, consisting of grading, drainage, granular base and hot mix paving, along Highway #2 west of Colborne. The Company owns several rock quarries and gravel pits, and produces various aggregates on a

commercial basis. On contract 81-18 the Company elected to produce the required 48,000 ton granular "A" aggregates from one of its sand and gravel pits, known as Smith Pit, located some 2 miles north of the contract.

Prior to commencing granular "A" production, Mr. Mark King, Vice-President of the Company, indicated that they would carry out process control sampling and testing of this material, in compliance with M.T.C. requirements.

Acceptance of base and subbase aggregates at this contract was specified by the 1980 guidelines. Acceptance sampling and testing was carried out by M.T.C. contract personnel on a lot by lot basis. The recommended lot size according to the guidelines is 4,000 ton or one day's production whichever is less. The guidelines further specify that the lots be subdivided into four sublots, taking one random sample at each sublot. The lot is deemed to be acceptable if the mean of the four test results falls within the specification limits, provided that the range of the four tests is not greater than the specification range. Non conforming lots are to be removed from the work, except those lots having sufficiently small deviation from the specification. The latter lots are allowed to be incorporated in the work at an appropriately adjusted price.

Guidelines for the aggregate producer's process control sampling and testing were set up in compliance with the acceptance procedures.

3. Production of Granular "A" Aggregates

Smith Sand and Gravel Pit is located in Lot 11, Concession II of Haldimand Twp. The granular inventory number of the pit is T 7-118. The height of the pit face from where the material was extracted was about 3 - 5 m, the depth of stripping over the granular being a maximum of 0.6 m. A typical portion of the pit face is shown in Figure 1.

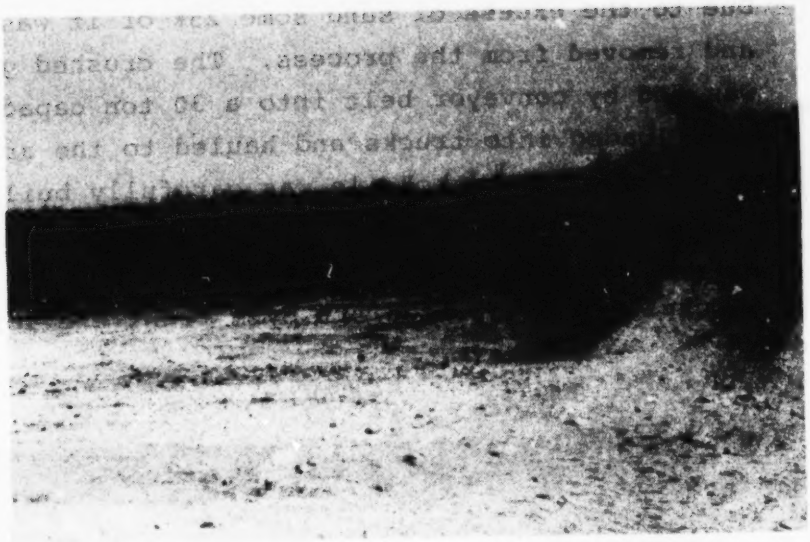


Figure 1.
Pit Face. Smith Sand & Gravel

By visual examination the material at the face was described as a gravelly sand with some cobbles, having a maximum size of approximately 150 mm. The gravel content (larger than 4.75 mm) was estimated to be 40%. The material was excavated from the face with a Catapilar 980-B type front end loader, having a capacity of 5½ cu. yd. (Imperial designation). The excavated material was dumped into a hopper and fed to a Cedar Rapid Commander - 855 model portable crusher unit, having a 5 ft x 16 ft. size screen deck. (Figure 2).

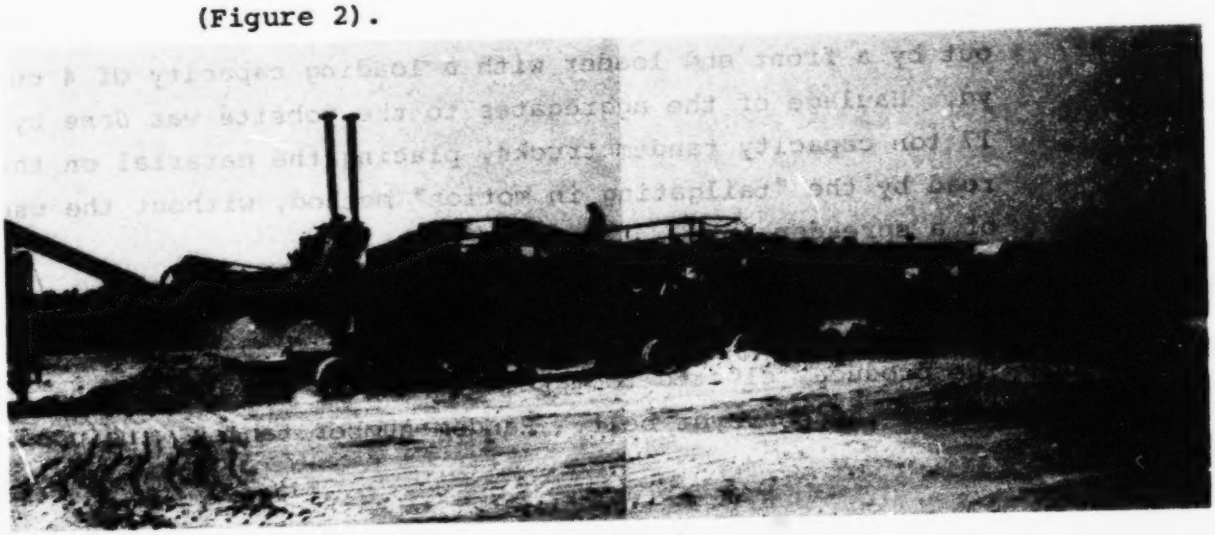


Figure 2.
Portable Crusher (Cedar Rapid)

Due to the excess of sand some 25% of it was screened off and removed from the process. The crushed granular "A" was fed by conveyor belt into a 30 ton capacity surge bin, then loaded into trucks and hauled to the area of the stockpile. The stockpile was carefully built by two trucks (23 ton and 13 ton capacity) according to the M.T.C. layer method. (Figure 3). Each new layer of the stockpile was levelled off by a front end loader.

Figure 3.
Stockpile before levelling off

Loading of the stockpiled material into trucks was carried out by a front end loader with a loading capacity of 4 cu. yd. Haulage of the aggregates to the jobsite was done by 17 ton capacity tandem trucks, placing the material on the road by the "tailgating in motion" method, without the use of a spreader box.

4. Sampling and Testing by the Producer

The producer elected to take two samples per day at the end of the conveyor belt. Random number tables were used

by the sampler to determine the exact time when the sample was to be obtained. Samples were collected in a five gallon pail, being passed through the flow of material, until the required sample size of 35 kg (±) was secured. All the samples were delivered to the testing laboratory located in Harnden & King's asphalt plant, some 21 km from Smith pit.

The testing laboratory is a 2 m by 4 m wooden building serviced with electricity but not with running water. (Figure 4).

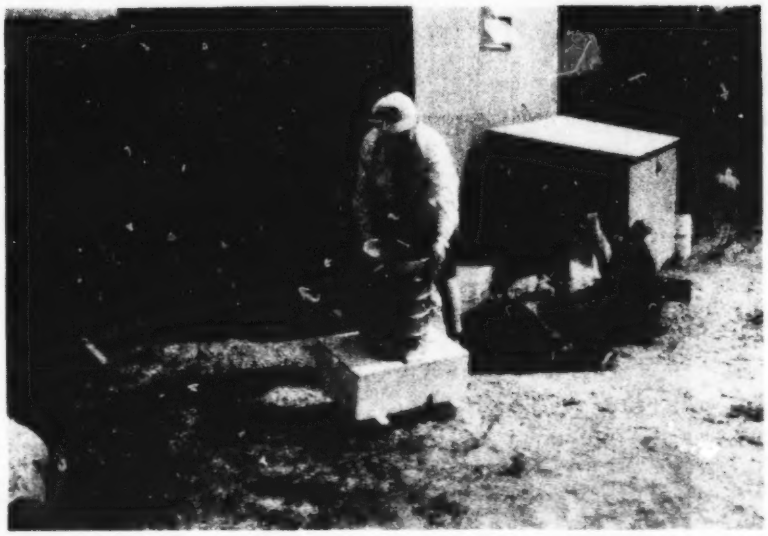


Figure 4.
External view of Testing Laboratory

The laboratory is provided with sieves, hot plates, balance, etc., to carry out full gradation tests. In order to achieve close duplication of test procedures with the M.T.C. field laboratory, some testing equipment was supplied by the Engineering Materials Office for the duration of the pilot study. The coarse aggregate portion of the sample was sieved by the use

of a rocker box, while for the lack of an electric shaker, the fine aggregate was sieved by hand, shaking the nest of fine sieves for the required time. Washing the fine aggregates took place at the weigh house about 15 m from the laboratory, where the nearest water supply was available. The samples were dried by using a hot plate. An internal view of the laboratory is shown in Figure 5. The laboratory technician, Mr. Casey Elliott, who performed all the tests has had several years of experience in doing sieve analysis. Upon completion of a test the results were submitted to Harnden & King's Head Office, where further computations and plotting of results on M.T.C. provided forms were carried out by Mr. Mark King.

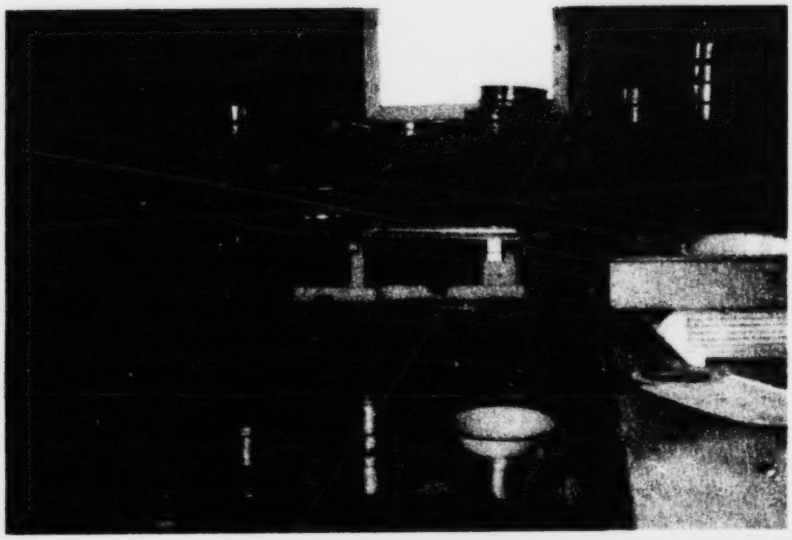


Figure 5.
Internal view of producer's laboratory

The producer carried out a total of 36 gradation tests during the production of granular "A" aggregates. Since the total quantity supplied for this contract was 48,000 ton, each test represented roughly 1,400 ton of materials. Grouping the tests in chronological order into lots, the 34 tests would equal 8.5 lots, each lot consisting of some 5,600 ton of processed granular "A" aggregates.

During sampling and testing operations close liaison with the producer was maintained by this office and several field visits were made by a senior technician.

5. Sampling and Testing by M.T.C.

Acceptance sampling and testing of the granular "A" was carried out by M.T.C. construction personnel. The produced and used 48,000 ton of aggregates were divided into 11 lots, each containing 4 sublots and taking one sample from each sublot. Lot and sublot sizes were determined on time basis, the exact time of taking samples being established by random number tables.

The samples were taken at the stockpile. At the appropriate time, determined by random tables, the last placed three truckloads of aggregates were levelled and mixed with a front end loader. The inspector then filled the sample bag from the levelled portion of the last loads.

The field laboratory consisted of a trailer, located next to the field office. The laboratory trailer was well equipped, having a microwave oven, Gilson and Rotap electrically operated shakers for the coarse and fine aggregates respectively, sample splitter, etc. The laboratory was supplied with running water, hydro, heating and air conditioning. The Ministry has carried out a total of 48 tests, each test representing approximately 1,000 ton of produced aggregates. It is to be noted, that two lots were sampled from an existing stockpile, produced prior to this contract. Since the material source and the process of both stockpiles was similar, all the test results were used for the analysis.

6. Analysis and Evaluation of Test Results

Since the acceptance criterion for gradation is based on the mean value and the range of the lot, statistical analysis was performed on lot data, rather than on individual test results.

In Table 1 lot mean statistics are shown for both Harnden & King's and M.T.C.'s "percentage passing" of each designated sieve results. The grand mean column shows the average percentage passing of all the lots for both sets of tests. The standard deviation is, of course, a measure of dispersion of data values, whereas the 99% confidence limits indicate the upper and lower % passing limits within which 99% of all the material falls. It is to be emphasized that the confidence limits are theoretical values and since we had only 9 to 12 lots to analyze the actual lot averages had a much narrower dispersion (spread) than the theoretical. The results of the same analysis are also plotted graphically on gradation charts (Figures 6 and 7) separately for the producer's and for M.T.C.'s results. In the graphs the actual extreme lot averages are also marked, indicating that every lot value fell within the specification limits, thus all the lots were acceptable at the contract price.

The theoretical total dispersion of the lot means, shown by the $\bar{\bar{x}} \pm 3\ \delta$ lines in the gradation charts, falls outside the specification on the fine limit of the 4.75 mm sieve. The total % outside specification was calculated to be 4.8%. We can, therefore, assume that if we have 100 lots there may be some 5 lots slightly outside the specification. Simultaneously having say 20 lots we will have a probability that one lot may not meet specification and would be accepted at a slightly reduced price.

By examining the tables and diagrams we will notice that the grand average gradations ($\bar{\bar{x}}$) of the lots for both sets of values are remarkably similar. The % passing the 4.75 mm sieve of Harnden and King's tests was 47.3%, while the M.T.C. tests resulted in 49% passing. The corresponding values on the 75 µm sieve were 4.0% for the producer and 4.7% for M.T.C.

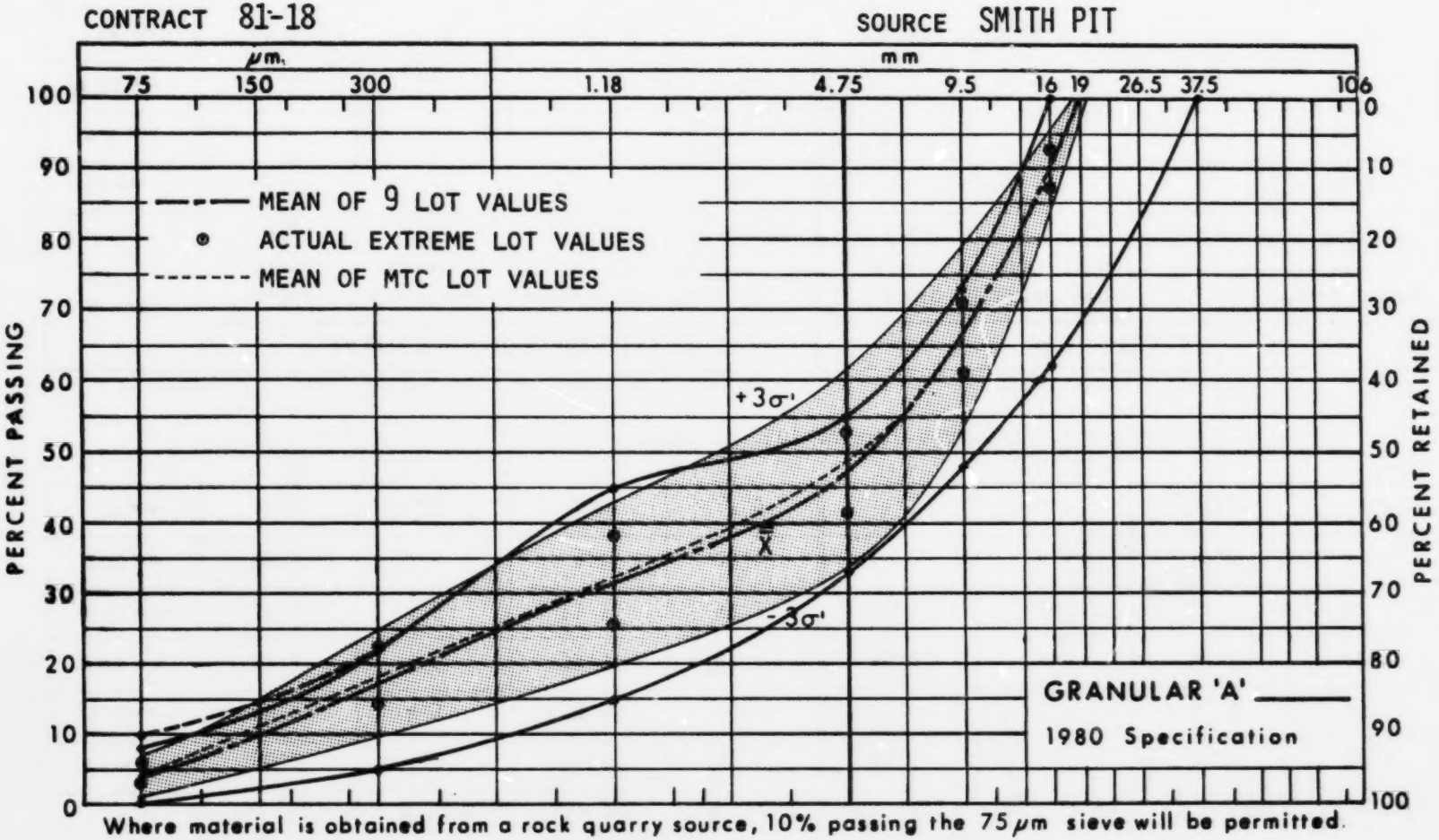
The overall variation of the lot means, measured by the standard deviations (δ), was marginally larger by the

SIEVE SIZE	HARNDEN AND KING'S TESTS				M.T.C. TESTS			
	GRAND MEAN (% PASSING) $\bar{\bar{X}}$ (%)	STANDARD DEVIATION σ' (%)	99 % CONFIDENCE LIMITS		GRAND MEAN (% PASSING) $\bar{\bar{X}}$ (%)	STANDARD DEVIATION σ' (%)	99 % CONFIDENCE LIMITS	
			$\bar{\bar{X}} - 3\sigma$	$\bar{\bar{X}} + 3\sigma$			$\bar{\bar{X}} - 3\sigma$	$\bar{\bar{X}} + 3\sigma$
16 mm	90.2	1.8	84.8	95.6	90.6	1.7	85.5	95.7
9.5 mm	66.2	4.3	53.3	79.1	67.0	2.7	58.9	75.1
4.75 mm	47.3	4.6	33.5	61.1	49.0	3.9	37.3	60.7
1.18 mm	31.2	3.9	19.5	42.9	32.4	3.4	22.2	42.6
300 μm	16.9	2.5	9.4	24.4	18.0	1.8	12.6	23.4
75 μm	4.0	1.0	1.0	7.0	4.7	0.5	3.2	6.2

TABLE 1 - LOT AVERAGE ANALYSIS

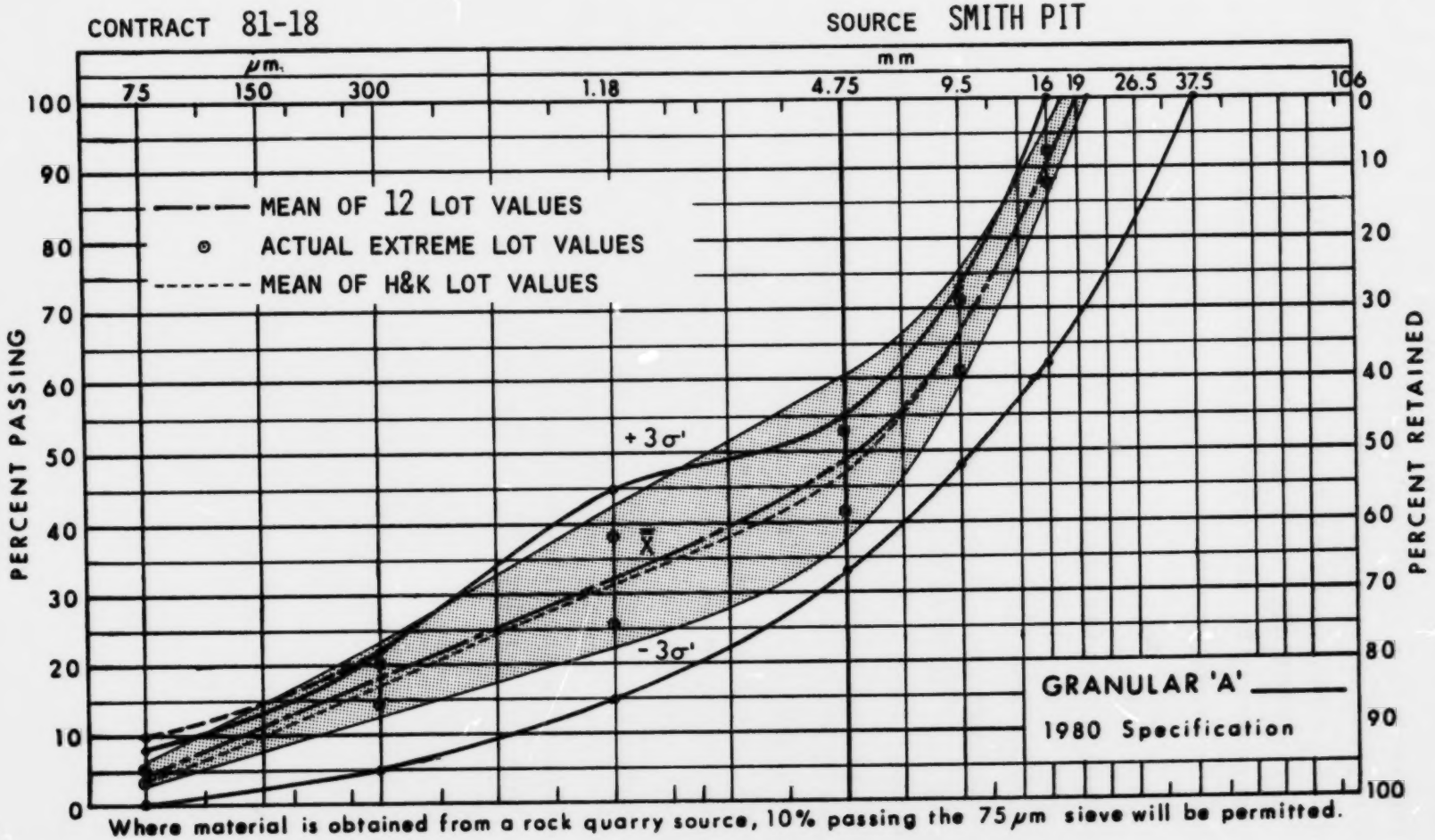
SIEVE SIZE	HARNDEN AND KING'S TESTS				M.T.C. TESTS			
	GRAND MEAN $\bar{R}$ (%)	STANDARD DEVIATION σ' (%)	99 % CONFIDENCE LIMITS		GRAND MEAN $\bar{R}$ (%)	STANDARD DEVIATION σ' (%)	99 % CONFIDENCE LIMITS	
			$\bar{R} - 3\sigma$	$\bar{R} + 3\sigma$			$\bar{R} - 3\sigma$	$\bar{R} + 3\sigma$
16 mm	3.7	2.1	0	10.0	4.4	3.4	0	14.6
9.5 mm	9.6	3.3	0	19.5	9.2	4.0	0	21.2
4.75 mm	12.6	4.2	0	25.2	10.0	4.4	0	23.2
1.18 mm	10.4	4.9	0	25.2	8.9	4.1	0	21.2
300 μm	6.0	3.1	0	15.3	4.7	3.4	0	14.9
75 μm	1.8	0.5	0.3	3.3	1.1	0.5	0	2.6

TABLE 2 - RANGE ANALYSIS



HARNDEN & KING GRADATION TEST ANALYSIS OF 9 LOTS

Fig. 6

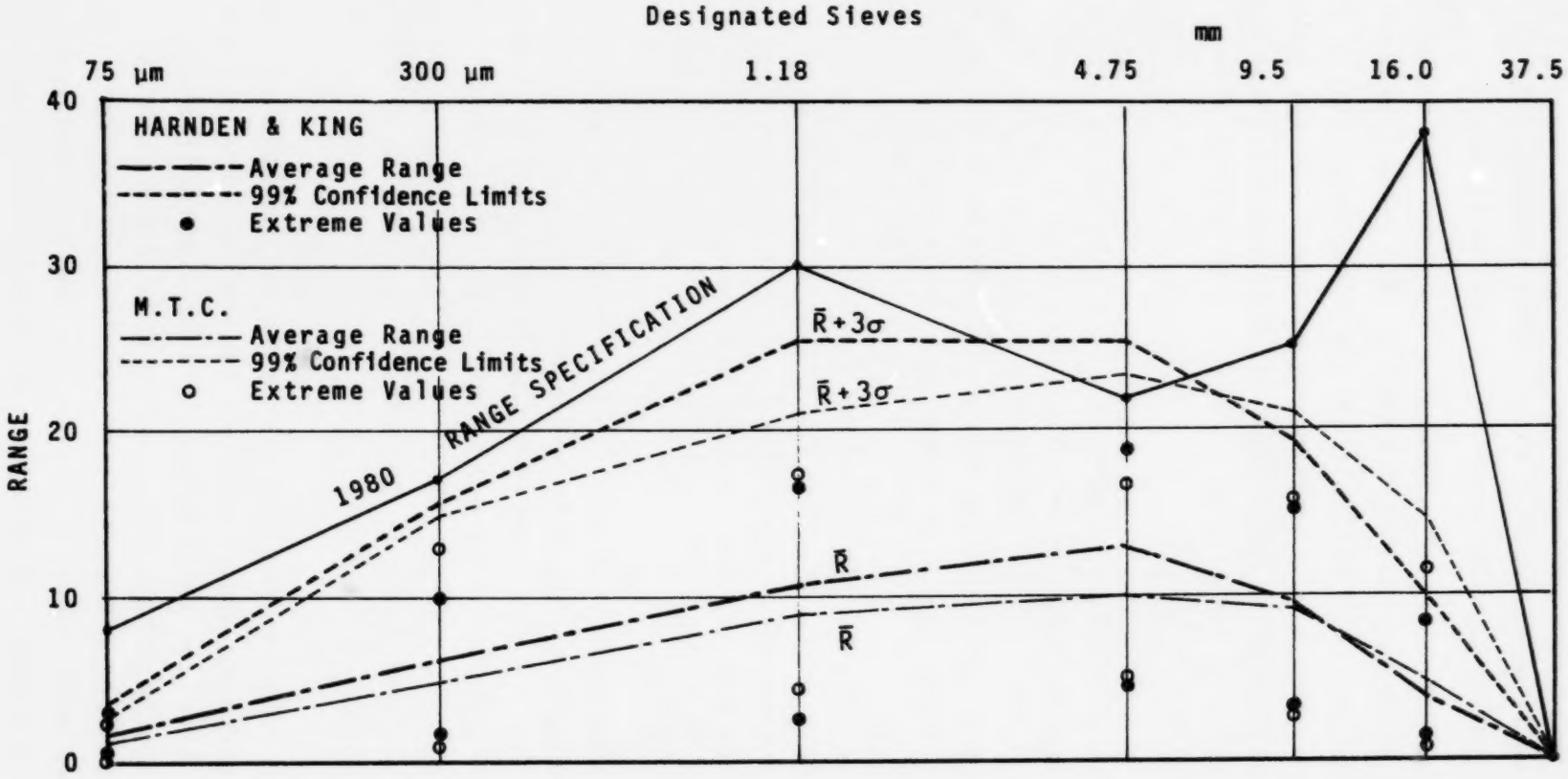


M.T.C. GRADATION TEST ANALYSIS OF 12 LOTS

Fig. 7

producer's tests than by M.T.C. The reason for this somewhat larger variation may be caused by the producer's testing technique (hand shaking of the sieves). Since, however, the producer sampled at the end of the conveyor belt and M.T.C. sampled the stockpiled material, the test results clearly indicate, that no undue segregation of the material occurs when the stockpile is carefully constructed by the M.T.C. layer method.

The results of the range analysis are marked in Table 2 and also plotted graphically in Figure 8. The range, defined as the difference between the highest and lowest % passing value of the sublots, is a measure of the variation within one lot. Range statistics were also found to be very similar when comparing the two sets of results. The average ranges ($\bar{R}$) computed by Harnden and King and by M.T.C. tests are almost identical, and they are significantly smaller than the 1980 allowable ranges on all designated sieves. The extreme range values were also well within the allowable limits. The statistical total dispersion, shown by the $\bar{R} + 3\delta$ line in Figure 8 is a few % outside the allowable range of 22% on the 4.75 mm sieve. The total % outside the range criterion is only 1.3%, i.e. roughly one lot among 100 would have a range higher than the allowable and thus would be accepted with a few % reduction of the contract price.



RANGE COMPARISON'S

Fig. 8

7. DISCUSSION AND CONCLUSIONS

From the Process Control Pilot Study presented in this report the following conclusions may be drawn:

(a) The granular "A" aggregates supplied for this M.T.C. contract by Harnden & King Construction Limited were well within the acceptance requirements of the 1980 guidelines. All the lots complied with both the lot mean and the range criteria, thus were accepted with 100% contract price.

(b) The producer has carried out a very close process control during the entire operation by sampling and testing the aggregates according to M.T.C. twice per day. No charges were made to the Ministry by the producer for the additional work.

(c) Analysis of the producer's and M.T.C.'s test results showed that the two sets of data were statistically equivalent. All of the producer's test results were within the normal variation (dispersion) of the material.

(d) It is felt that some improvement of the producer's laboratory would be necessary for an eventual certification for acceptance of laboratory and test methods. The Vice-President, Mr. Mark King, indicated that the company would be willing to carry out laboratory improvements in order to be qualified for process control.

(e) In order to minimize the risk to the client, quality assurance specifications usually provide for some control on the producer's sampling and testing program. Highway Agencies retain the right to examine producer's test results and control charts and make observations of the sampling and testing techniques. Some agencies carry out periodic

correlation sampling and testing, plotting their test results on the producer's control chart, to determine conformance. Some highway departments perform regular but infrequent acceptance tests. Regardless of the method of control, in all those cases where the producer (contractor) has a reliable and well run quality control scheme, the highway agencies sampling and testing frequencies are drastically reduced.

At this pilot study M.T.C. carried out a full acceptance program, so that duplicate sets of test results could be evaluated and compared. Such frequent testing would not, of course, be necessary had the producer had an approved process control system.

To prove this point the assumption was made that M.T.C. carried out spot check testing only, say one test per lot instead of the specified four. In Figure 9, a control chart, representing the 4.75 mm sieve is presented. On the chart the lot values and the ranges of the producer's tests are marked. One individual test result was then randomly selected from each of the M.T.C. lots. These individual tests, together with the moving average values, are also plotted on the charts. By examining the charts it can easily be seen that all the moving averages of the assumed spot check tests meet the specification requirements and they are all well within the natural variations of the process. The grand mean ($\bar{\bar{x}}$) and the average range ($\bar{R}$) of M.T.C. original lots and the assumed spot tests are identical, the grand mean of both being $\bar{\bar{x}}$ = 49.0% and the average range $\bar{R}$ = 10.0%. It may thus be concluded that the validity of the producer's process control tests could have been reliably controlled by the assumed spot checks by M.T.C., resulting in 75% savings in sampling and testing time.

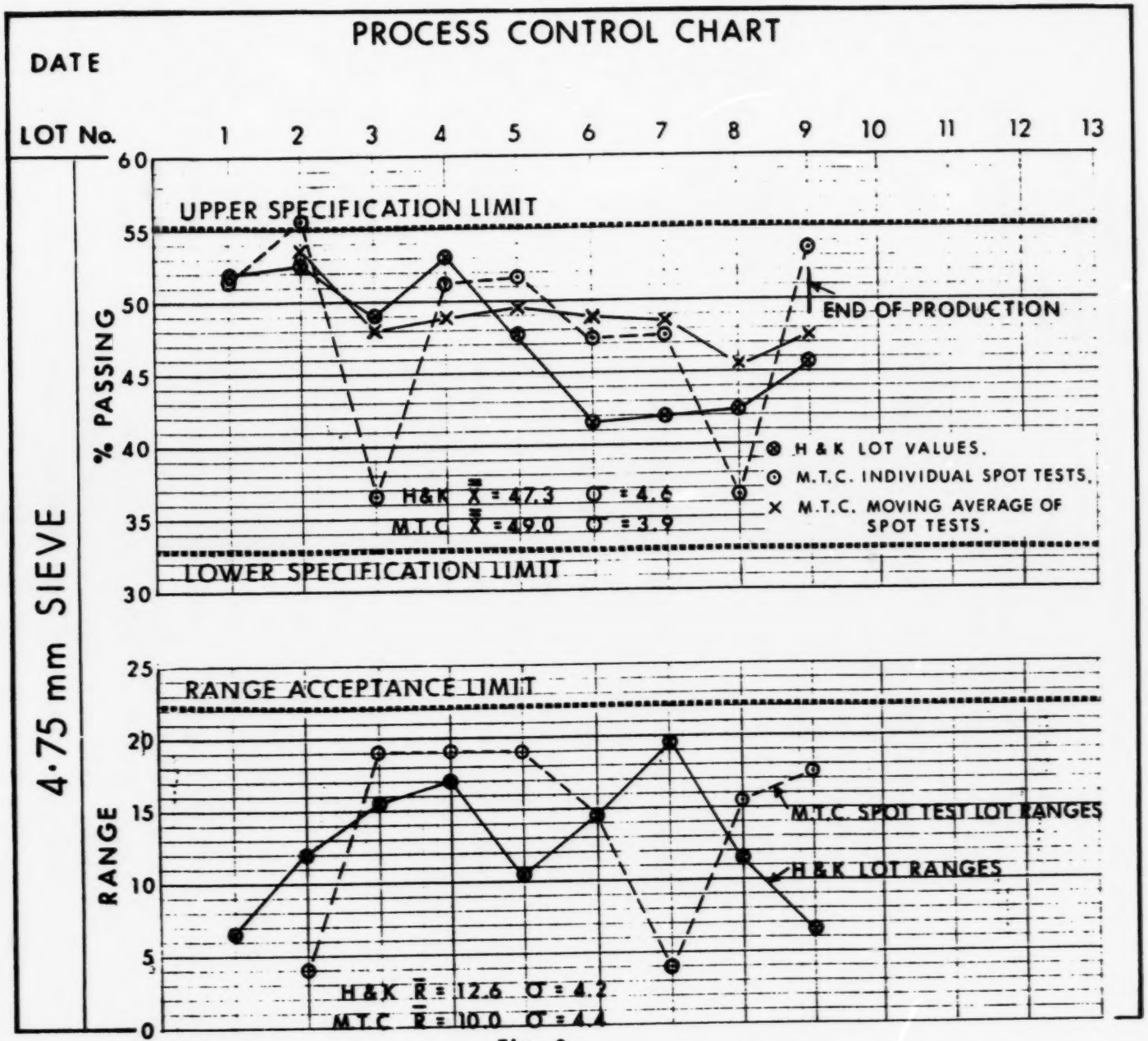

PROCESS CONTROL CHART
DATE
LOT No.
1 2 3 4 5 6 7 8 9 10 11 12 13
4·75 mm SIEVE
% PASSING
60 55 50 45 40 35 30
UPPER SPECIFICATION LIMIT
LOWER SPECIFICATION LIMIT
END OF PRODUCTION
H & K LOT VALUES.
M.T.C. INDIVIDUAL SPOT TESTS.
M.T.C. MOVING AVERAGE OF SPOT TESTS.
H&K X̄ = 47.3 σ = 4.6
M.T.C X̄ = 49.0 σ = 3.9
RANGE
25 20 15 10 5 0
RANGE ACCEPTANCE LIMIT
M.T.C. SPOT TEST LOT RANGES
H & K LOT RANGES
H&K R̄ = 12.6 σ = 4.2
M.T.C R̄ = 10.0 σ = 4.4

Fig. 9

8. ACKNOWLEDGEMENTS

Grateful appreciation is expressed to the staff of Harnden and King Construction Company and in particular to Mr. Mark King, Vice-President, for their eager and conscientious participation and co-operation in the Pilot Project. Mr. H. R. Reed of the Soils and Aggregates Section of M.T.C. assisted in the statistical analysis and documentation of this report. His contribution is duly acknowledged.

Report No. 2 81 12 16

PROCESS CONTROL PILOT STUDY ON GRANULAR A GRADATION BY GENSTAR STONE PRODUCTS INC. - NELSON QUARRY

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1. Introduction

This report contains the description, analysis and evaluation of one of the completed pilot studies carried out by Genstar Stone Product Inc. at the Nelson Quarry location in north Burlington.

2. Description of the Project

King Paving and Materials, a Division of Flintkote Company of Canada and now a part of Genstar Stone Products Inc. was the successful bidder on Contract 81-20, consisting of grading, drainage, granular base and hot mix paving, along Highway #5 from 0.4 miles west of Guelph line, westerly to 0.25 miles west of Evans Avenue. The Company is now one of Ontario's leading

producers of crushed stone and owns several sources for producing various aggregates on a commercial basis. On Contract 81-20 the Company elected to produce the required 75,500 tons of Granular A material from Nelson Quarry.

Nelson Quarry is Genstar's largest producing quarry being established in 1953 on a 500 acre site on the Niagara Escarpment in north Burlington.

Mr. A.L. Hartman, Manager of Nelson Quarry expressed interest in participating in a sampling and testing program with M.T.C. Accordingly,senior technicians of this office visited the quarry on several occasions in order to co-ordinate sampling and testing procedures.

Acceptance of base and subbase aggregates at this contract was specified by the 1980 guidelines. Acceptance sampling and testing was carried out by M.T.C. contract personnel on a lot by lot basis. The recommended lot size according to the guidelines is 4,000 ton or one day's production whichever is less. The guidelines further specify that the lots be subdivided into four sublots, taking one random sample at each sublot. The lot is deemed to be acceptable if the mean of the four test results falls within the specification limits, provided that the range of the four tests is not greater than the specification range. Non conforming lots are to be removed from the work, except those lots having sufficiently small deviation from the specification. The latter lots are allowed to be incorporated in the work at an appropriately adjusted price.

Guidelines for the aggregate producer's process control sampling and testing were set up in compliance with the acceptance procedures.

3. Production of Granular A Aggregate

In providing graded aggregates five main operations are carried out at Nelson Quarry:
- stripping, drilling, blasting, crushing and shipping.

The material blasted from the rock face is loaded on 50-ton Euclid trucks by a P & H electric-powered seven cubic yard shovel. (Figure 1).

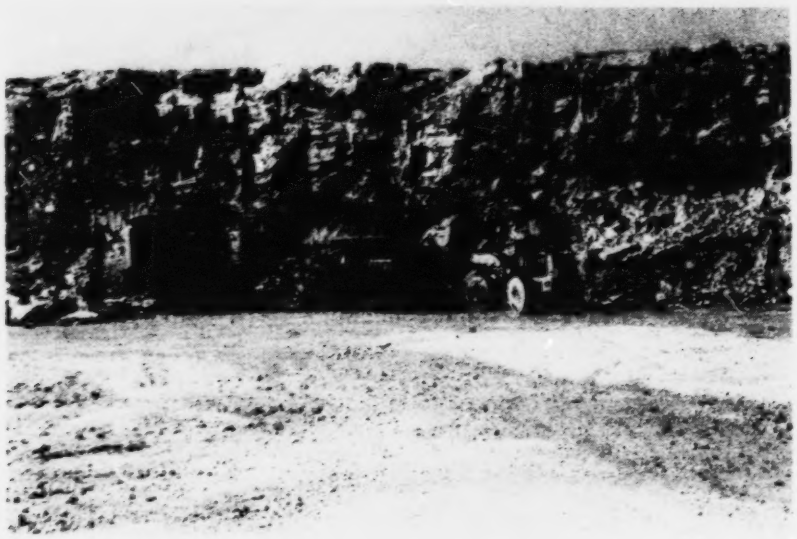


Figure 1: Quarry face and loading operation

These trucks transfer the stone from the quarry face directly to the primary crusher (a 42" Traylor Gyratory Crusher*) where it is reduced in size to approximately six inches and then conveyed to a surge pile.

From the surge pile, stone is conveyed to the secondary crushing and screening plants, where it is further reduced and screened to produce a wide range of products.

Most of the finished product is then conveyed to stockpiles located over reclaiming tunnels. (An extensive underground network where material can be drawn off when required).

* Equipment and machinery are imperial standards.

A 36" main conveyor transports the product (see Figure 2) from the tunnel network to truck loading bins having nine 100 ton capacity compartments (Figure 3).

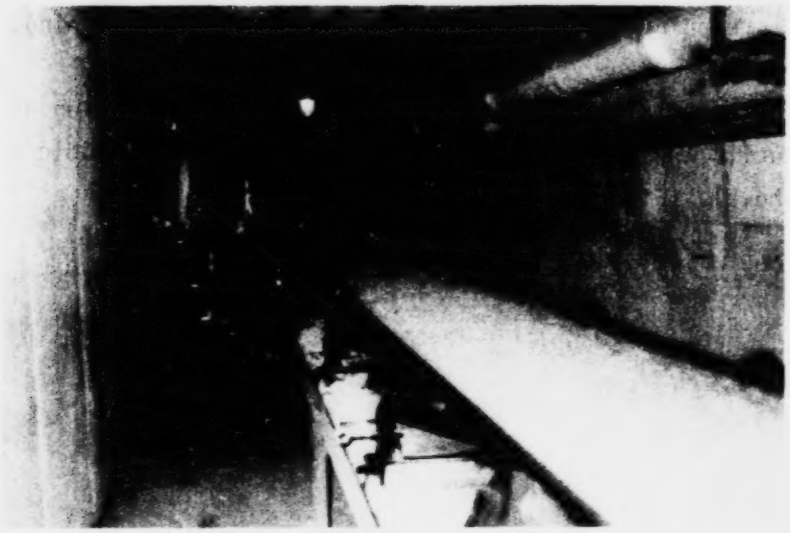


Figure 2: Tunnel network main conveyor

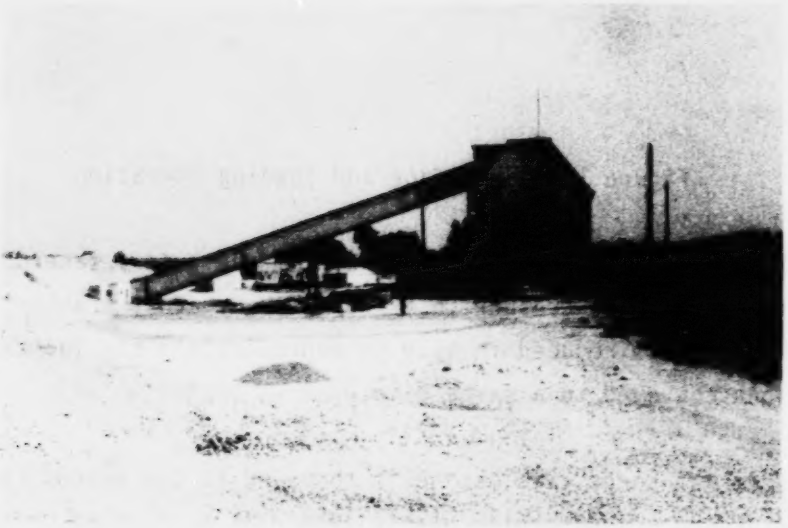


Figure 3: Truck loading bins

The Granular A aggregates were transported by trucks from the loading bins for stockpiling using the M.T.C. layer method. Delivery trucks were loaded by a front end loader from the stockpile.

At Nelson Quarry all orders are handled on site by a micro-computer, which provides order desk and dispatch personnel with up to date information on customer orders, dispatch schedules, products and truck movements. All daily transactions are recorded for daily processing through the company's main computer.

4. Sampling and Testing by the Producer

The laboratory, located at the quarry is spacious, modern and well equipped, as shown in Figures 4 - 8 inclusive.

While the testing technician (Mr. K. Paul) had only six months experience in gradation testing, he performed the tests conscientiously and was most eager to accept suggestions for improvements.

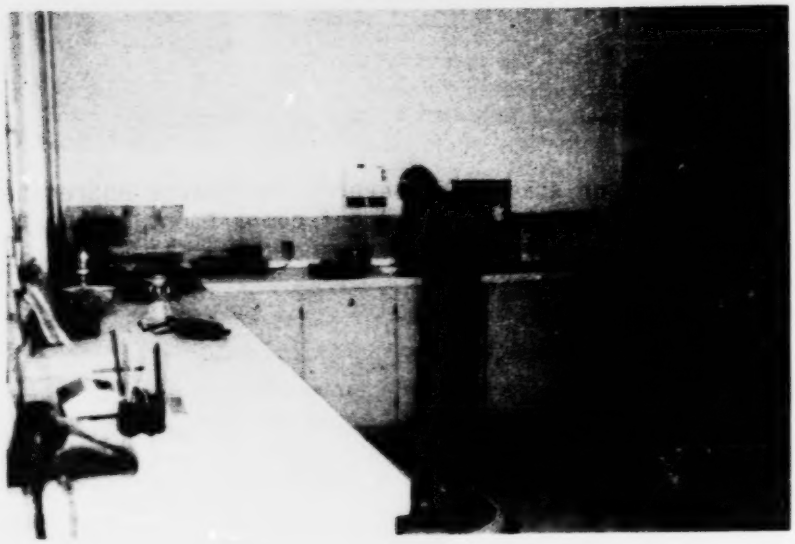


Figure 4: Testing lab.

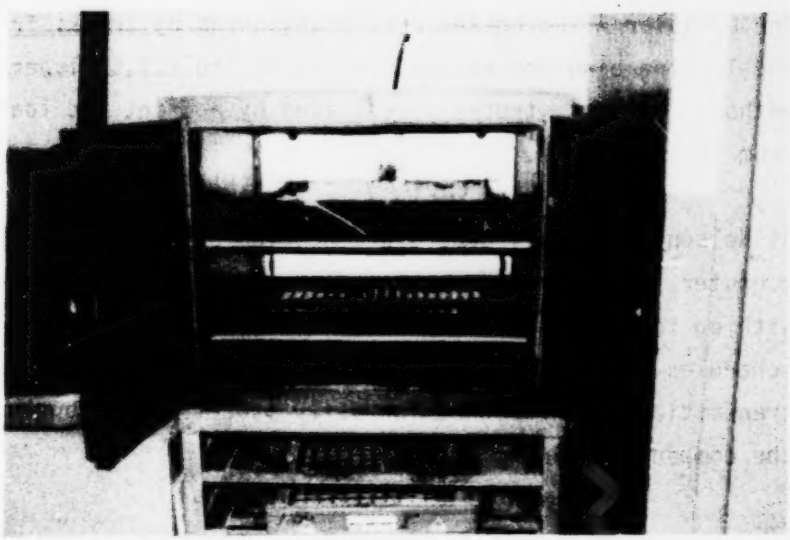


Figure 5: Oven for drying samples

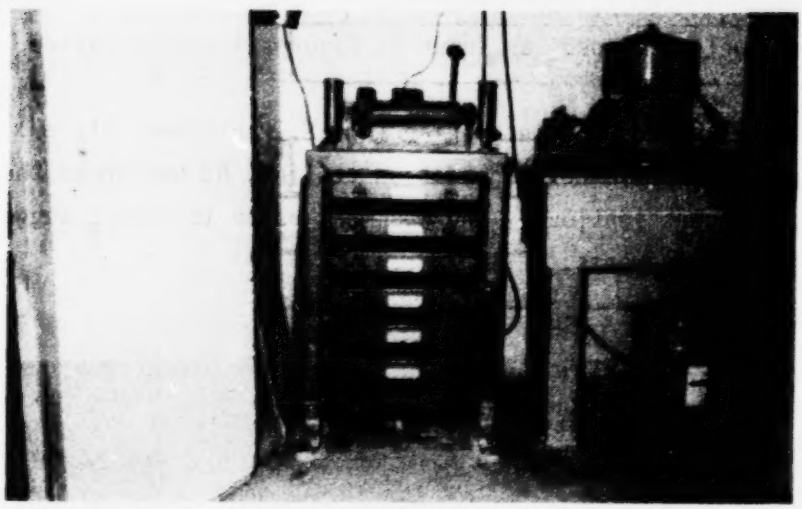


Figure 6: Gilson shaker and screens for coarse aggregate sieving, has sound proof compartment and dust evacuator.

Figure 7: Weighing coarse aggregate portion. Rotap for fine aggregate sieving on right side.

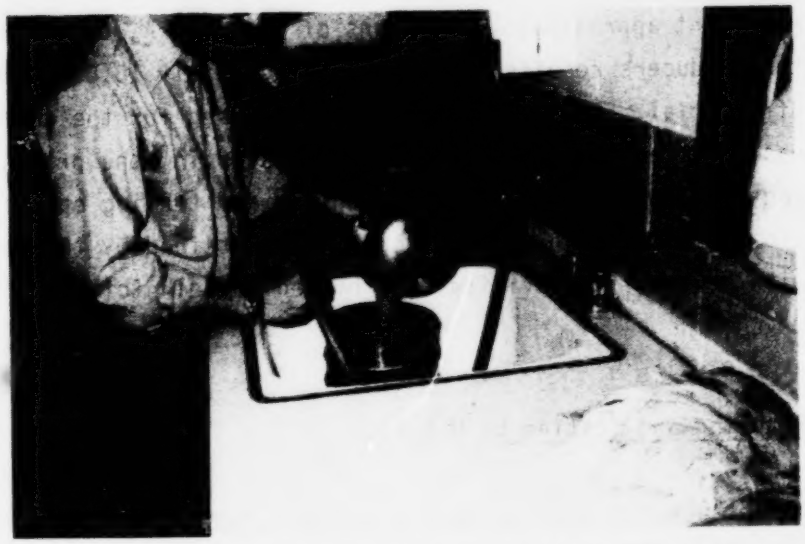


Figure 8: Technician carrying out washing procedures for fine aggregate portion of gradation test.

An instruction package for process control was left with the technician, that included sampling and testing procedures as well as recording forms and control charts.

The producer elected to take two samples per day at the Granular A stockpile being produced for the M.T.C. contract. Random number tables were used to determine the time the sample was to be obtained. Samples were taken by the testing technician from the next truck to place material into the stockpile. The load was dumped then levelled off and five or six shovel fulls were taken from across the levelled area to obtain the 35 kg field sample required.

Eight lots were completed by the producer for a total of 30 gradation tests covering the period from July 13 to October 21, 1981. Production of Granular A was intermittent according to the requirements. Each test was estimated to represent approximately 600 tons of Granular A, therefore the producer's results represent approximately 18,000 tons of material. The remaining quantities used for the contract was produced and stockpiled prior to starting the process control program. During the sampling and testing operations close liaison with the producer was maintained by this office with several field visits made by senior technicians.

5. Sampling and Testing by M.T.C.

Acceptance Sampling was preformed by a technician of the consultant McCormick and Rankin. Using random tables, samples were obtained at the location of delivery, by dropping the last loads of the front end loader on the ground and then sampled across the levelled material. Testing was carried out by an M.T.C. technician in a mobile laboratory located at Palermo.

The field laboratory was well equipped with up to date equipment, having a microwave oven, electrically operated shakers for coarse and fine aggregate sieving, running water, hydro, heating and air conditioning.

The Ministry carried out preliminary sampling and testing in April with production sampling and testing starting on June 8, 1981. Some 44 gradation tests were performed representing approximately 1,000 tons/test. Of the eleven lots computed for acceptance, one lot was outside specifications 3.1% on the coarse side of the 4.75 mm sieve, all remaining lots met the acceptance criteria.

6. Discussion and Analysis of Test Results

Since the acceptance criterion for gradation is based on the mean value and the range of individual tests within a lot, statistical analysis was performed on lot data rather than on individual test results.

In Table 1 the distribution of lot means are given for the producer's as well as for M.T.C. tests. The column "mean" ($\bar{\bar{X}}$) represents the mean of the population on each designated sieve. The 95% conformance gives the limits of gradation within which 95% of all the theoretical gradation falls.

SIEVE SIZE	GENSTAR LOT ANALYSIS				M.T.C. LOT ANALYSIS			
	MEAN $\bar{\bar{X}}$	STAND. DEVIATION σ	95% CONFORMANCE $\bar{\bar{X}} + 2\sigma$	$\bar{\bar{X}} - 2\sigma$	MEAN $\bar{\bar{X}}$	STAND. DEVIATION σ	95% CONFORMANCE $\bar{\bar{X}} + 2\sigma$	$\bar{\bar{X}} - 2\sigma$
16 mm	73.2	3.6	80.4	66.0	75.0	5.1	85.2	64.8
9.5 mm	56.9	4.7	66.3	47.5	59.0	6.1	71.2	46.8
4.75 mm	40.8	4.3	49.4	32.2	40.9	5.4	51.7	30.1
1.18 mm	21.4	2.4	26.2	16.6	20.6	2.6	25.8	15.4
300 µm	12.3	1.3	14.9	9.7	11.9	1.3	14.5	9.3
75 µm	9.1	0.8	10.7	7.5	8.0	0.9	9.8	6.2

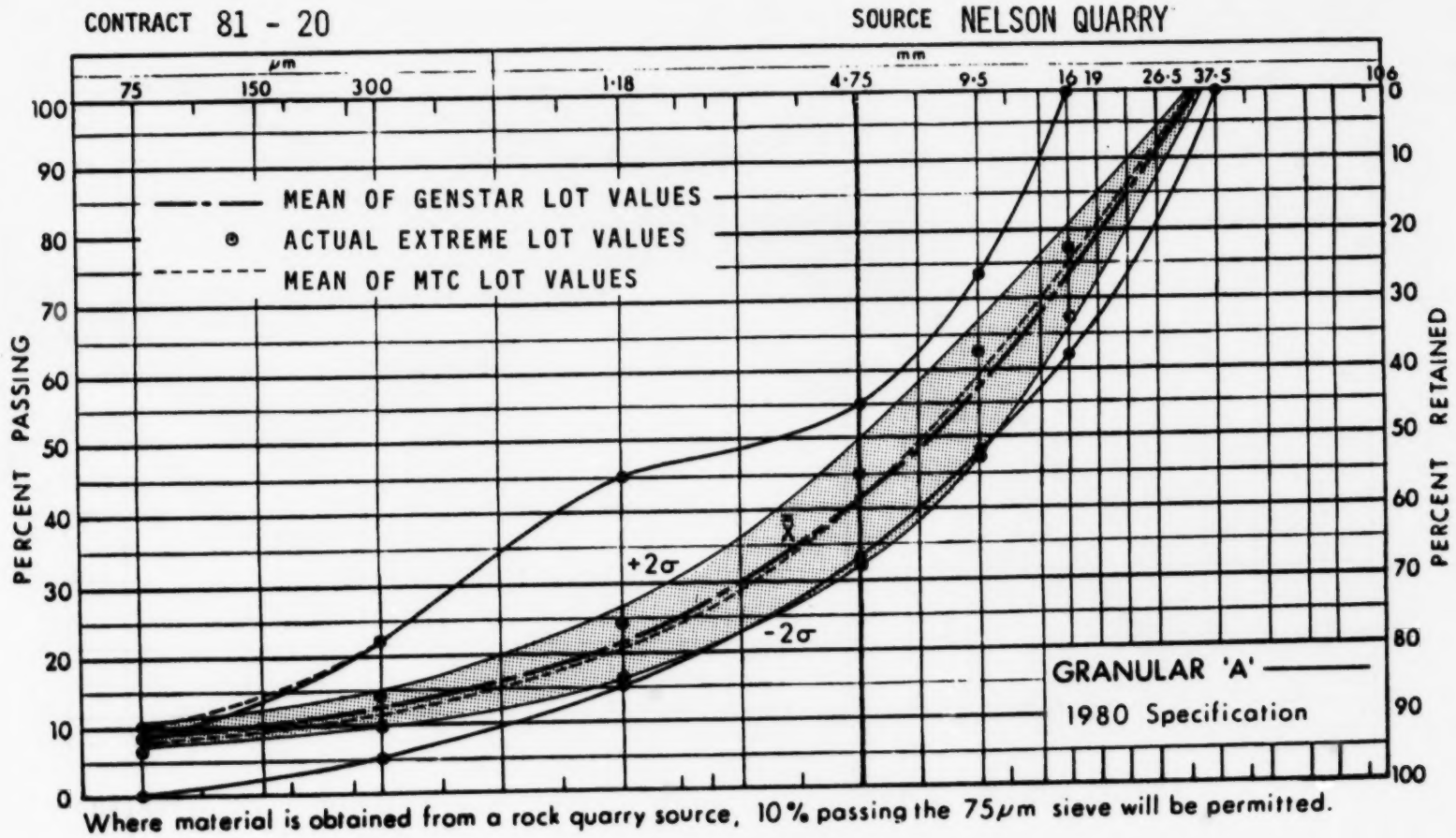
Table 1 - Gradation Lot Analysis
(% Passing)

The producer had only 8 lots tested, M.T.C. tested 11 lots, consequently the dispersion of the lot means was considerably narrower than the theoretical one. Only one lot was proven slightly out of specification on the 4.75 mm sieve on the gradation requirement. This outside specification lot was picked up by both producer's as well as M.T.C. tests. The population mean and the distribution of the mean at 95% confidence limits are marked on gradation charts as shown on Figures 9 and 10. The actual extreme lot values are also plotted, all well within the 95% theoretical limits.

To accept or reject material the Engineer is interested only whether the lot mean and range is within the acceptable limits or not. However in order to control the production of the aggregates (crushing, stockpiling, loading, etc.) and to ensure that the specification requirements are met an analytical control by means of statistical probability is essential.

Table 1 for instance indicates to the producer that the average gradation of the aggregates remained very similar before and after stockpiling. But it also flashes a warning that some segregation has taken place in stockpiling, which is manifested by the larger standard deviations (σ) calculated by the M.T.C. test results.

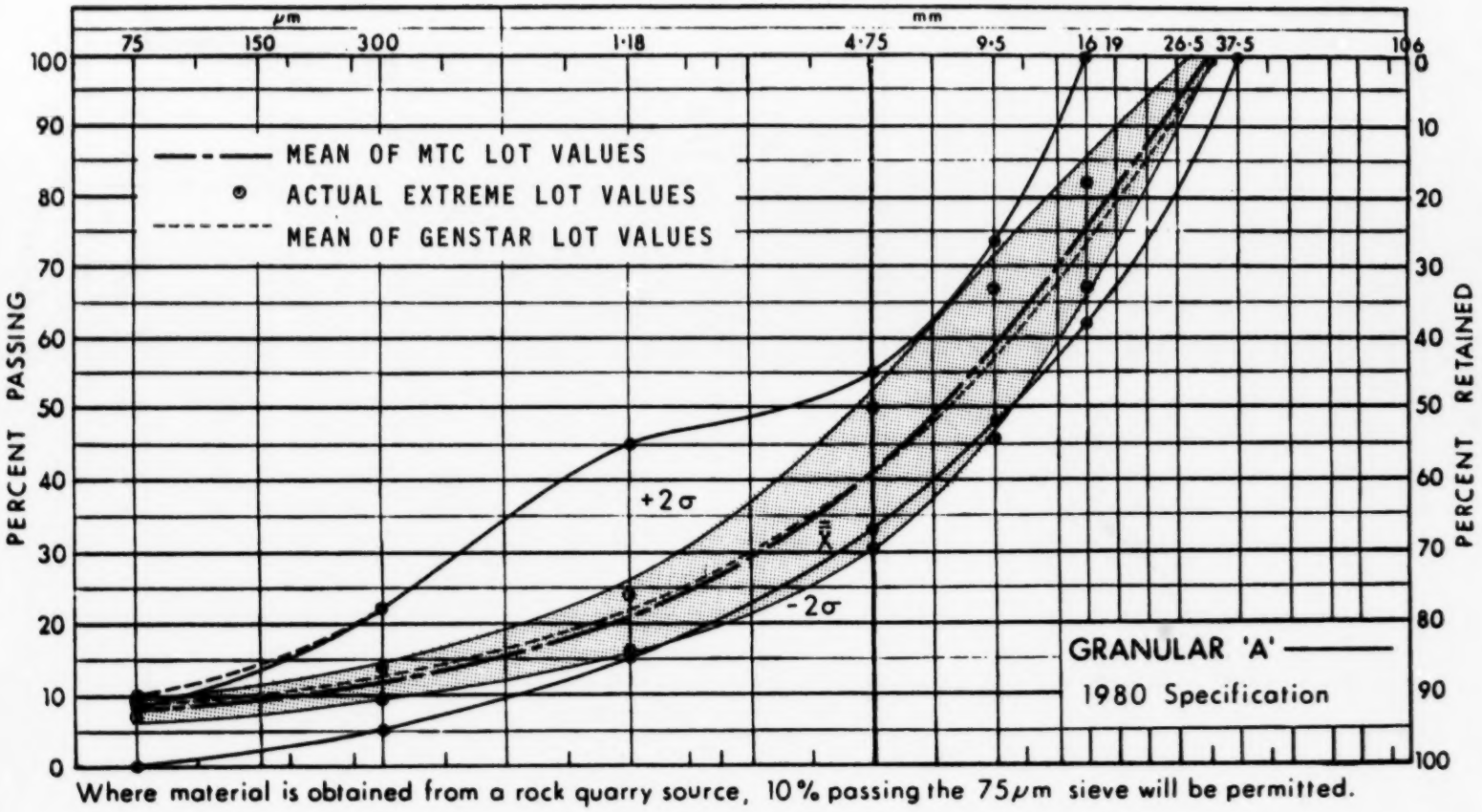
This segregation is even more pronounced by examining the range statistics (See Table 2). The average range ($\bar{R}$) and the distribution of ranges ($\bar{R} + 2\sigma$) were found to be much larger by tests carried out after stockpiling than before. While on the basis of acceptance criterion only two lots were slightly outside on the range, statistical analysis implies that had we had more lots to accept there would have been several lots having larger than the acceptable range on the 9.5 mm and the 4.75 mm sieves.



GENSTAR GRADATION TEST RESULTS OF 8 LOTS

Fig. 9

CONTRACT 81 - 20 SOURCE NELSON QUARRY



Where material is obtained from a rock quarry source, 10% passing the 75μm sieve will be permitted.

MTC GRADATION TEST RESULTS OF 11 LOTS

Fig. 10

SIEVE SIZE	GENSTAR RANGE ANALYSIS				M.T.C. RANGE ANALYSIS			
	MEAN $\bar{R}$	STAND. DEVIATION σ	95% CONFORMANCE		MEAN $\bar{R}$	STAND. DEVIATION σ	95 % CONFORMANCE	
			$\bar{R} + 2\sigma$	$\bar{R} - 2\sigma$			$\bar{R} + 2\sigma$	$\bar{R} - 2\sigma$
16 mm	9.0	4.3	17.6	0.4	15.1	9.0	33.1	0
9.5 mm	9.1	4.0	17.1	1.1	18.8	8.4	35.6	2
4.75 mm	6.7	4.5	15.7	0	16.1	8.1	32.3	0
1.18 mm	3.5	2.4	9.3	0	10.2	5.6	21.4	0
300 µm	2.4	1.5	5.4	0	5.8	3.1	12.0	0
75 µm	1.9	1.0	3.9	0	3.7	2.1	7.9	0

Table 2 - Gradation Range Analysis

The above exercise appears to confirm the importance of controlling the material production at an early stage (say from the conveyor belt) and of more frequent quality control sampling at the location of loading the aggregates for delivery to the work.

Regardless of the above discussion it is to be pointed out that the supplier produced an acceptable Granular A and carried out the suggested gradation tests accurately, the latter which is demonstrated by the very similar means of the two sets of values.

When the gradation of the produced aggregates are controlled by the producer by methods acceptable to the highway agency the latter usually specifies that the quality control test results shall be used for acceptance purposes. In these cases the highway agency carries out monitoring testing to perform some statistical comparison. The most widely used method for such a comparison is called hypothesis testing. While the discussion of this method is outside the scope of this report, suffice is to say that by means of some hypothesis testing the mean and the variability of a larger number of test data can reliably be compared with a much smaller set of data.

This method is used for instance by the Virginia D.O.T. in monitoring the producer's test results. Two statistical

tests are made:

1.) to determine if the variability, as measured by the monitoring tests exceeds the variability as measured by the producer's tests and

2.) to determine if the mean as established by the monitoring tests differ from the mean of the producer's tests.

Virginia specifies that the D.O.T. takes two monitoring tests per week during production of the aggregates and these two tests are statistically compared with the producer's test results for the same period.

In order to check the reliability of the producer's test results the Virginia method of calculation was carried out using only 10 M.T.C. randomly selected tests against the 30 tests of the producer. The long hand computation of this hypothesis testing is rather cumbersome when a large number of data is analysed. A computer program can simplify the process considerably. The weekly computations proved that the variability and the mean of both sets of results were statistically comparable, so that all test results represented the same population. (Hypothesis testing based on the "F" distribution can be found in any textbook on basic statistics. A brief description of the Virginia computations is available in this office).

7. Conclusions

From the pilot study on the aggregate producer's sampling and testing program on Granular A gradation the following conclusions may be drawn:

(a) The producer's technician carried out random sampling of the aggregates at the required frequency at the time when the material was placed into the stockpile.

(b) Gradation testing was performed in the quarry laboratory according to the standard M.T.C. method. The quarry laboratory is in excellent condition and well equipped. The testing technician while having limited experience in gradation testing, performed the tests conscientiously and meticulously.

(c) M.T.C. carried out a full acceptance testing program in accordance with the 1980 guidelines at the time the material was loaded on the delivery trucks.

(d) Statistical comparison of the producer's and M.T.C. test results proved that both sets of data represented the same population, so that the producer's test results were acceptable.

(e) The analysis also indicated that there was some segregation of the material in the stockpiling process. This segregation did not effect the acceptability of the lots, but resulted in a larger variability of the end product than the variability of the aggregates when they were produced.

8. Acknowledgements

Grateful appreciation is expressed to the staff of Genstar's Nelson Quarry and in particular to Mr. A.L. Hartman, Manager, for their participation and co-operation in the Pilot Project. Mr. J.D. Dainton, former member of the Soils and Aggregates Section of M.T.C., assisted in the statistical analysis and documentation of this report. His contribution is duly acknowledged.

Report No. 3 82 02 10

PROCESS CONTROL PILOT STUDY ON GRANULAR A GRADATION BY WALKER INDUSTRIES - VINELAND QUARRY

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Appendix - Special Provision for Granular A, July 1981.

1. Introduction

This report contains the description, analysis and evaluation of one of the completed pilot studies carried out by Walker Industries at their Vineland Quarry location, Vineland, Ontario.

2. Description of Project

Bot Construction Limited, Oakville, Ontario was the successful bidder on Contract 81-72, consisting of grading, drainage, granular base, hot mix paving and structure at the Highway 406 and Q.E.W. location in St. Catharines. Bot Construction selected Walker Industries, Vineland Quarries to produce the required 148,000 tons of granular A material for the contract.

Vineland Quarries Ltd. is one of Walker Industries aggregate sources located in the Niagara Region, being established in 1958 and located just south of Vineland on the Niagara Escarpment. (Figure 1 and 2)

Figure 1 - Vineland Quarries, south of Vineland, Ontario.

Figure 2 - Vineland Quarries Office

Mr. John Cowan, Sales Manager of Vineland Quarries expressed interest in participating in a sampling and testing program with M.T.C. Accordingly, senior staff of this office visited the quarry and the testing lab. located at Walker Bros. Quarry in Thorold on several occasions in order to co-ordinate the sampling and testing procedures.

Acceptance for gradation and percent crushed particles of Granular A aggregates was specified by special provision in this contract. A copy of the special provision, is attached in the Appendix at the end of this report. Requirements pertaining to lot size, acceptable gradation bands and ranges, adjusted payment scale etc. are included in the special provisions.

Guidelines for the Aggregate Producer's process control sampling and testing were set up in compliance with the acceptance procedures.

3. Production of Granular A Aggregates

In providing graded aggregates five main operations are carried out at Vineland Quarry:

- stripping, drilling, blasting, crushing and shipping.

The dolomite limestone material is drilled and blasted from the rock face and loaded on 50-ton Euclid trucks by a 992-Caterpillar front end loader. (Figure 3).

Figure 3 - Working West Face, showing loading operation

These trucks transfer the stone from the quarry face directly to the primary crusher (a Jefferies Impact - Figure 4) where it is reduced in size and conveyed to a double deck screening operation (Figure 5).

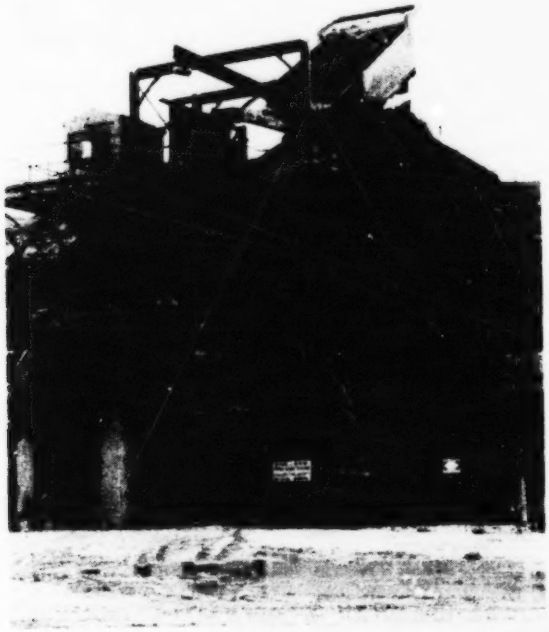


Figure 4 - Truck dumping into Primary Crusher

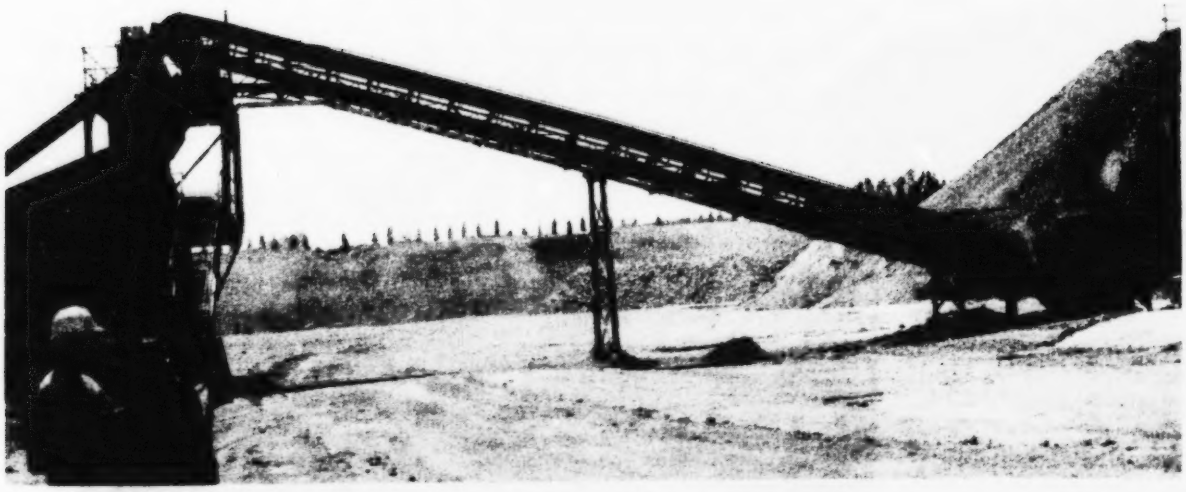


Figure 5 - From Primary Crusher to a Double Deck Screening operation

From this screening operation, oversize material (>37.5 mm) is conveyed and stockpiled for further secondary crushing and screening (Figure 6). The pass 37.5 mm (1½") material produces the specified granular A material, and is conveyed to a hopper then stockpiled by means of a radial stacker (Figure 7). The granular A is then removed by trucks, loaded by a front end loader (a Michigan 125B) for delivery to the job site.

Figure 6 - Oversize material (>37.5 mm) stockpiled in background Granular A product conveyed on left side to hopper.

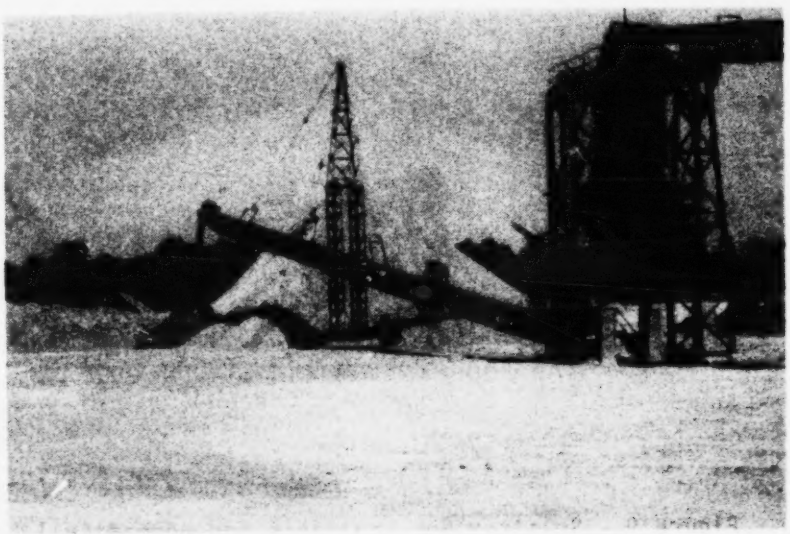


Figure 7 - Granular A aggregates conveyed from hopper by Radial Stacker for stockpiling.

4. Sampling and Testing by the Producer

While sampling was carried out at Vineland Quarry all testing was performed at the laboratory located in Walker Bros. Quarry, Thorold, Ontario.

The laboratory facilities are excellent, being supplied with well maintained, modern and up to date equipment (Figures 8-11 inclusive).

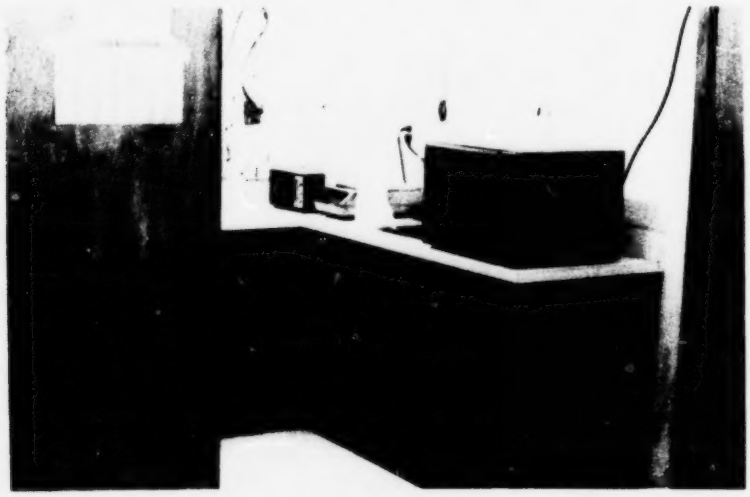


Figure 8 - Part of Testing Lab showing a new microwave oven for drying samples.

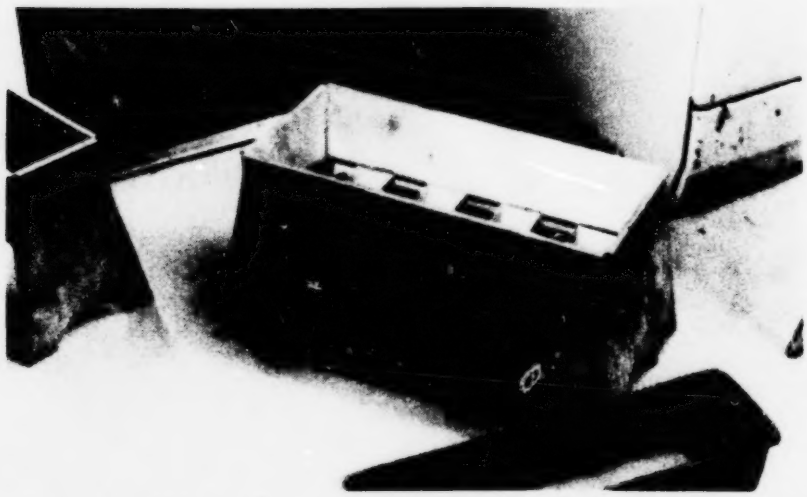


Figure 9 - Splitter Box, suitable for mechanically reducing pass 37.5 mm material to test portion size.

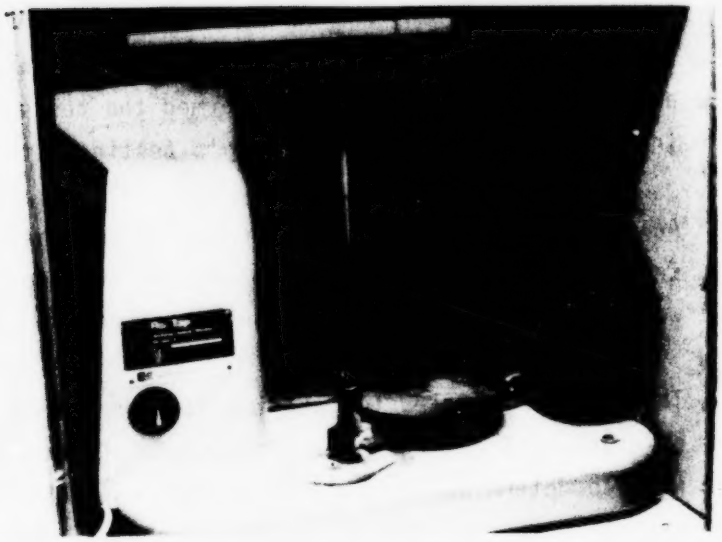


Figure 10 - Rotap for fine aggregate sieving, enclosed in a sound reducing cabinet.

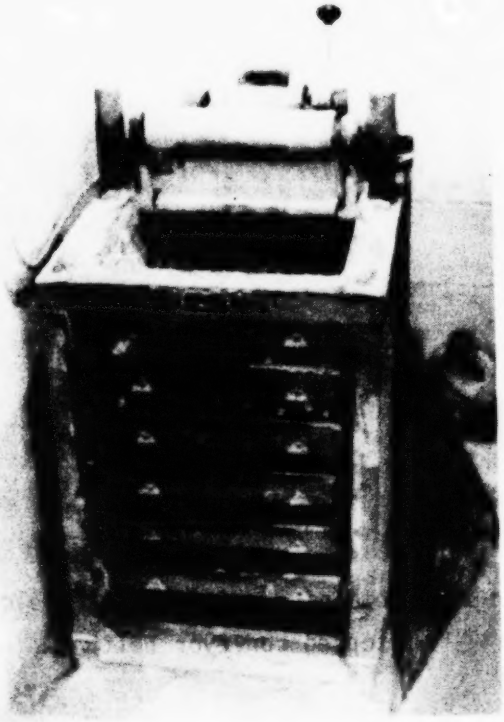


Figure 11 - Gilson Shaker and sieves for coarse aggregates is enclosed in a separate concrete block compartment having a dust evacuator.

Sampling and testing was carried out by Walker Industries Quality Control Technician, Mr. Mike Gillap, an experienced and capable technician who performed the tests conscientiously in conformance with the Ministry's testing methods and procedures.

An instruction package for process control was left with the technician, that included sampling and testing procedures as well as recording forms and control charts.

The producer elected to take two samples per day during production of granular A for the M.T.C. contract. Random number tables were used to determine the time the sample was to be obtained. Samples were taken by the Quality Control Technician by having the conveyor belt stopped and obtaining the field sample (approximately 35 kg) directly from the belt. (Figures 12, 13 & 14).

Figure 12 - Obtaining a Granular A Field Sample (35 kg) from stopped conveyor belt.

Sixteen lots were completed by the producer for a total of 64 gradation tests covering the period from August 24 to

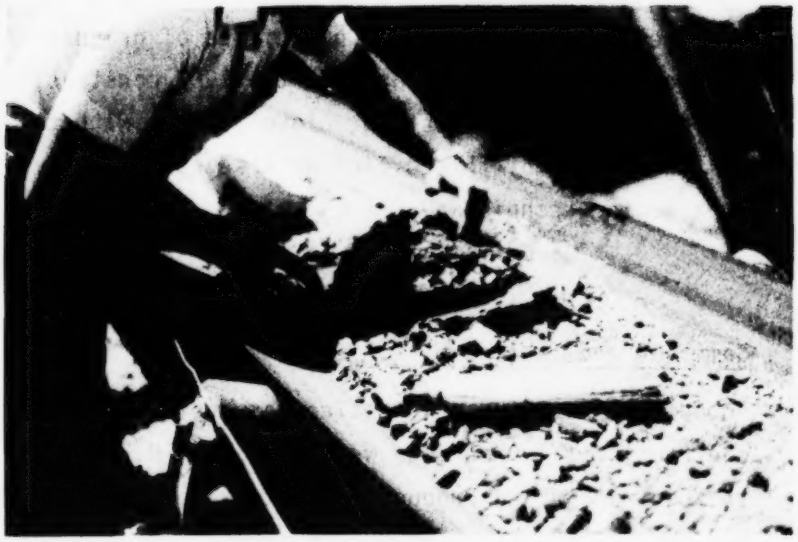


Figure 13 - Collecting the field sample from between two sets of rollers.

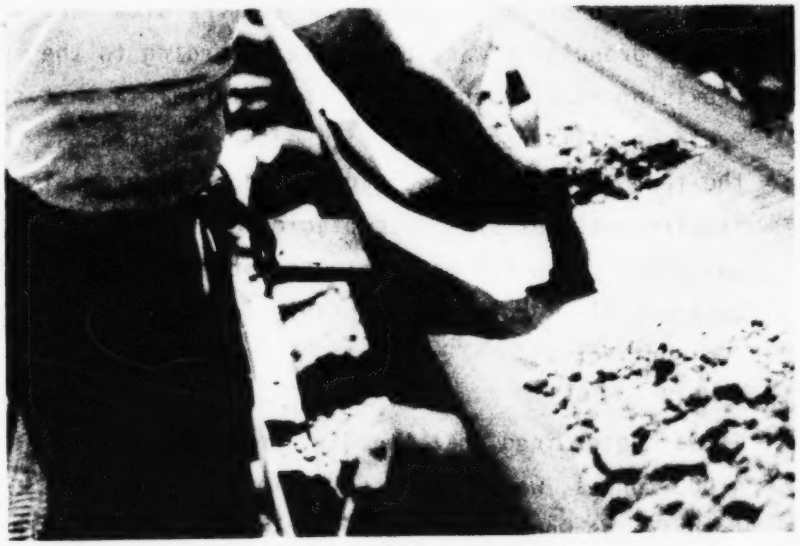


Figure 14 - Collecting the fines.

December 16, 1981. Each test was estimated to represent approximately 1500 to 2000 tons of granular A, therefore the producer's results represent approximately 112,000 tons of material. The remaining quantities of granular A will be produced at a later date for the 1982 construction season. During sampling and testing, close liaison with the producer was maintained by this office with several field visits made by a senior technician.

5. Sampling and Testing by M.T.C.

Acceptance sampling and testing was performed by M.T.C. contract staff. Meetings were held with M.T.C. staff the Contractor and Producer to determine sampling methods and procedures, as the producer was supplying a granular A for three contracts, two of the contracts to meet 1980 specifications and Contract 81-72 to meet the special provision requirements. It was agreed that the producer would produce a granular product to meet the special provision requirements and that a separate stockpile would be built for each days production. Material would not be used from a stockpile until the test results were known. If the granular A was acceptable according to the special provision requirements, then the material in that stockpile would be delivered to any of the three contracts. When the test results were outside the special provision requirements but still acceptable according to the 1980 guidelines then the material was not to be delivered to contract 81-72 but was acceptable for use on the other two contracts.

It was determined that one days production, approximately 4,000 tonnes, would represent a lot and that the M.T.C. technicians would take four samples per day from the stockpile as it was being produced. Using random numeric tables to determine the sampling time, samples were obtained from

the stockpile by having a front end loader dig into the stockpile (Figure 15) and remove several bucket fulls of material. The material in the pile would then be backbladed, to form a level area for sampling purposes (Figure 16). A field sample of approximately 35 kg would be obtained by taking five or six shovel fulls of material across the backbladed material using a proper sampling shovel. (Figure 17)

Figure 15 - Front End Loader removing material from stockpile, prior to sampling.

Figure 16 - Front End Loader backblading material in the stockpile for sampling purposes.

Figure 17 - M.T.C. personnel sampling the stockpile across the backbladed material.

All gradation tests were carried out in a mobile laboratory located at the intersection of Q.E.W. and Martindale Road. The field laboratory was well equipped with up to date equipment, having a microwave oven, electrically operated shakers, running water, hydro, heating and air conditioning.

Some 31 lots meeting the special provision requirements were produced from the 21st of August to the 11th of December 1981. 31 lots relate to 124 gradation tests representing approximately 1000 tonnes per test. Lots not meeting the special provision requirements were not included in the analysis as this material was not used on contract 81-72.

6. Discussion and Analysis of Test Results

Since the acceptance criterion for gradation is based on the mean value and the range of individual tests within a lot, statistical analysis was performed on lot data rather than on individual test results.

In Table 1 the distribution of lot means are given for the producer's as well as for M.T.C. tests. The column mean ($\bar{\bar{X}}$), represents the mean of the population on each designated sieve. The 95% conformance gives the limits of gradation within which 95% of all the theoretical lot values would fall.

SIEVE SIZE	WALKER'S LOT ANALYSIS				MTC LOT ANALYSIS			
	Mean $\bar{\bar{X}}$	Stand Dev. σ	95% Conform. $\bar{\bar{X}}+2\sigma$	$\bar{\bar{X}}-2\sigma$	Mean $\bar{\bar{X}}$	Stand. Dev. σ	95% Conform. $\bar{\bar{X}}+2\sigma$	$\bar{\bar{X}}-2\sigma$
19.0 mm	86.6	1.6	89.8	83.4	91.0	3.5	98.0	84.0
9.5 mm	57.1	1.7	60.5	53.7	61.7	3.2	68.1	55.3
4.75 mm	34.7	1.6	40.6	34.2	40.8	2.3	45.4	36.2
1.18 mm	18.8	1.2	21.2	16.4	21.4	1.9	25.2	17.6
300 µm	11.5	0.9	13.3	9.7	13.1	1.4	15.9	10.3
75 µm	7.1	0.7	8.5	5.7	8.0	1.0	10.0	6.0

Table 1 - Gradation Lot Analysis (% Passing)

Statistical analysis indicates that while all 16 lots tested by the producer met the special provision acceptance criterion for gradation, one could expect 6 lots out of every 100 to be outside specifications on the 4.75 sieve (1 in every 16 lots) and that all the remaining sieves would be within specifications more than 99% of the time. The same type of statistical analysis carried out for the 31 lots tested by the M.T.C. indicates that while all lots met the gradation requirements one could expect 2 lots out of 100 to be slightly outside specifications on the 75 µm sieve and that all the remaining sieves would be within specifications more than 99% of the time. However since the M.T.C. had several lots that did not meet the special provision and this material was not used for contract 81-72, the test results were not included in the analysis.

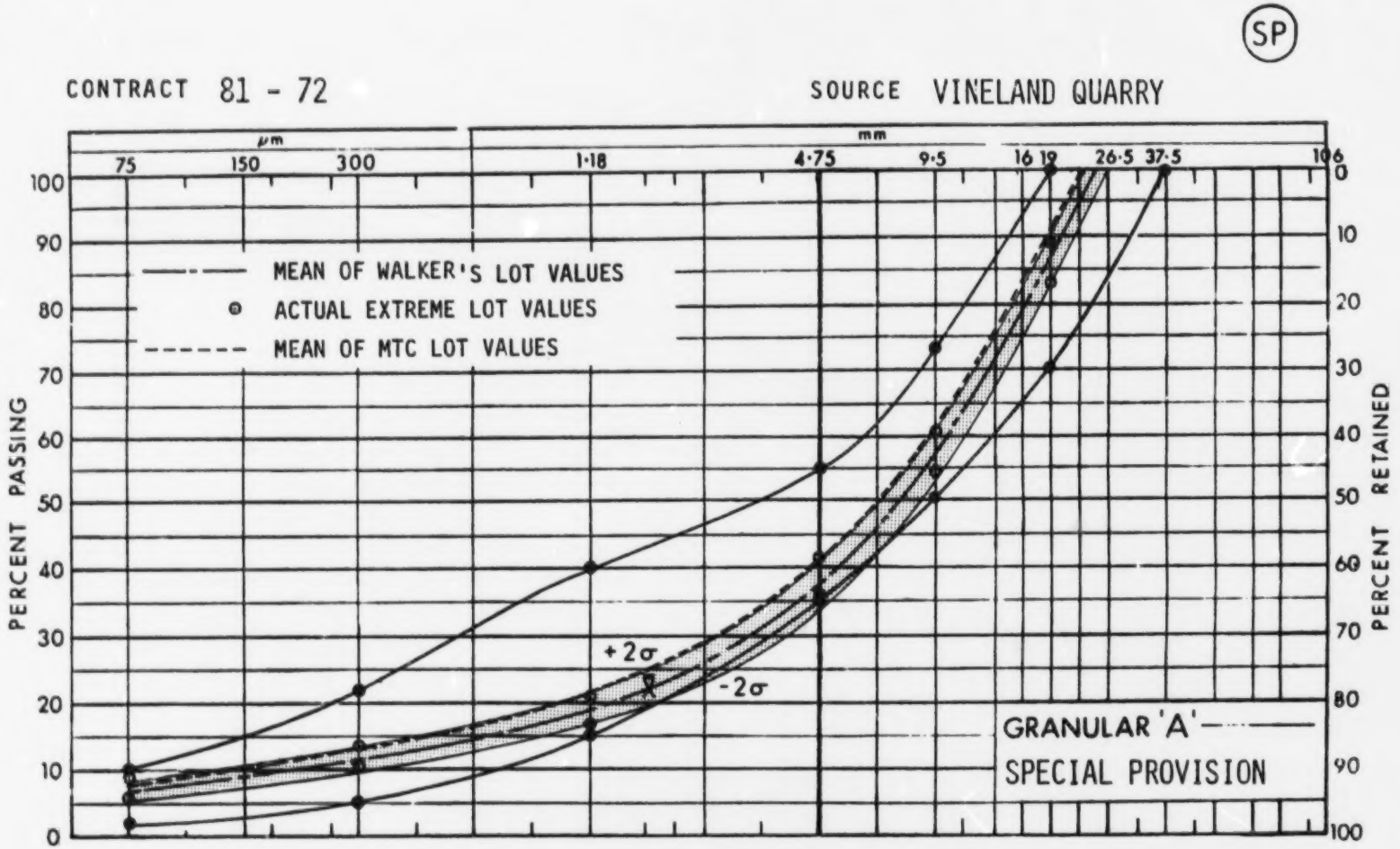
In further examining sample statistics (Table 1) it becomes obvious that while all the lots were within acceptable limits the mean gradation of the aggregate tested by M.T.C. shows a higher percent passing and a larger dispersion than the producers test results on every designated sieve. The larger percent passing and dispersion could be attributed to the additional processing and handling of the material prior to sampling at the stockpile. (Conveyor belt to hopper, hopper to stacker, stacker to stockpile, handling of material by front end loader prior to sampling).

The population mean and the distribution of the mean at 95% conformance limits are shown on gradation charts (Figures 18 & 19). The actual extreme lot values are also plotted. Most of the extreme values are at or within the 95% conformance limits with only one or two results being outside.

In Table 2 the distribution of lot ranges are given for the producer's as well as for M.T.C. The mean (R) column represents the average range of the individual tests within each lot for each designated sieve.

SIEVE SIZE	WALKER'S RANGE ANALYSIS				MTC RANGE ANALYSIS			
	Mean $\bar{R}$	Stand. Dev. σ	95% Conform. $\bar{R}+2\sigma$	$\bar{R}-2\sigma$	Mean $\bar{R}$	Stand. Dev. σ	95% Conform. $\bar{R}+2\sigma$	$\bar{R}-2\sigma$
19.0 mm	3.7	1.9	7.5	0	4.1	2.3	8.7	0
9.5 mm	6.3	3.4	13.1	0	8.1	3.2	14.5	1.7
4.75 mm	5.8	3.3	12.4	0	7.1	3.2	13.5	0.7
1.18 mm	3.9	2.0	7.9	0	5.8	3.1	12.0	0
300 µm	2.6	1.4	5.4	0	3.6	2.0	7.6	0
75 µm	2.1	1.2	4.5	0	2.4	1.2	4.8	0

Table 2 - Gradation Range Analysis



Where material is obtained from a rock quarry source, 10% passing the 75 μm sieve will be permitted.

Figure 18 - WALKER'S GRADATION TEST RESULTS OF 16 LOTS

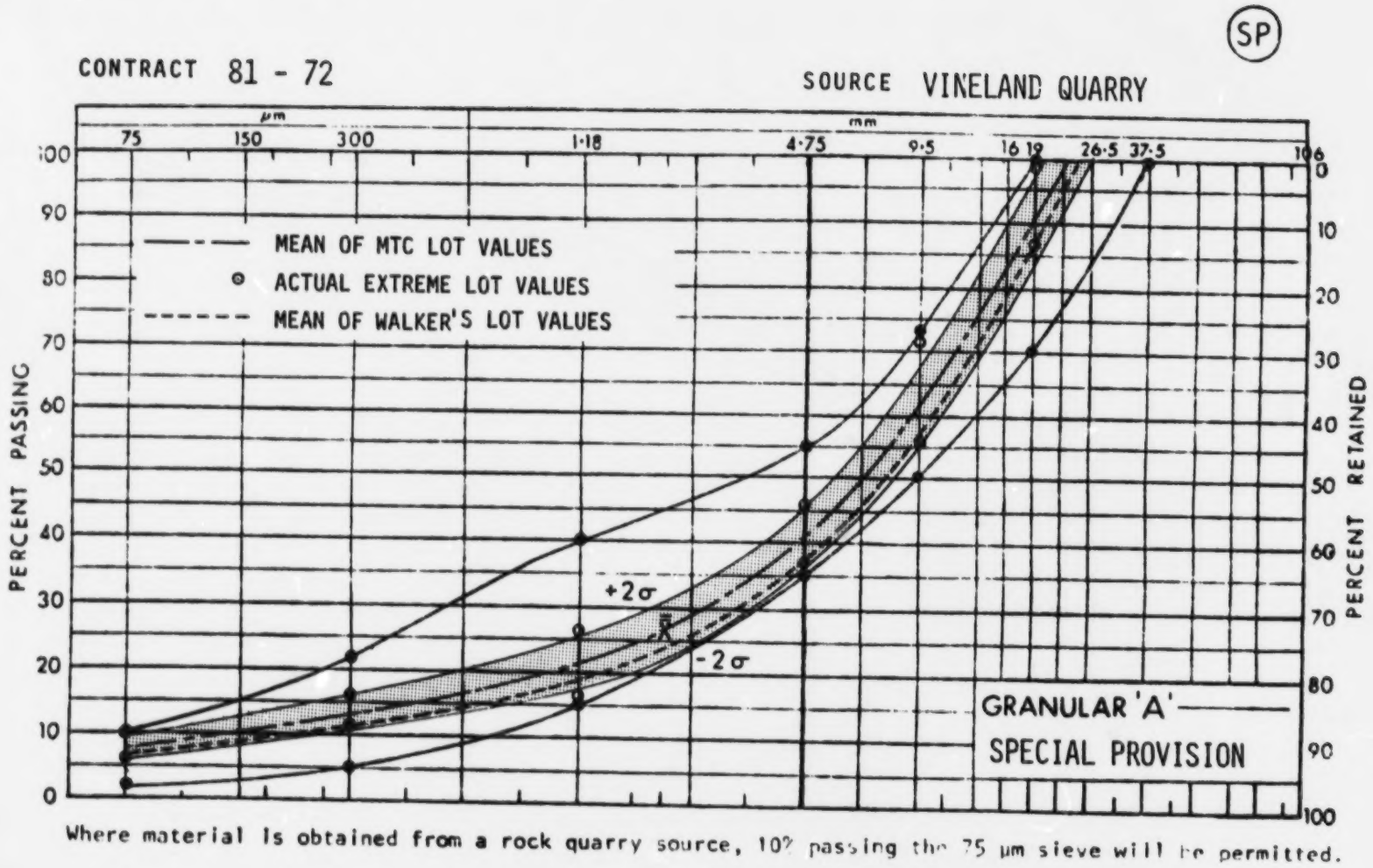


Figure 19 - MTC GRADATION TEST RESULTS OF 31 LOTS

By examining the range statistics in Table 2 it confirms what was expected that there is a greater variation of test results from samples taken from stockpiles than there is from stopped belt sampling. The average range ($\bar{R}$) and the distribution of ranges were found to be greater in tests carried out after stockpiling than before.

While on the basis of acceptance criterion the producer had only one lot very slightly outside the range specifications (0.1%) on the 75 µm sieve, statistical analysis implies that lots would meet the range specifications on all the sieves more than 99% of the time. Of the 31 lots analyzed for M.T.C. all lots met the range specifications. Statistical analysis of the M.T.C. results implies that 1 or 2 out of every 100 would be outside specifications on the 75 µm sieve. The lot ranges met the specification requirements more than 99% of the time on the remaining designated sieves.

Regardless of the above discussion it is to be pointed out that the supplier produced an acceptable Granular A product and carried out the suggested gradation tests accurately which is demonstrated by the similar gradation of the two sets of values.

7. Conclusions

From the pilot study on the aggregate producer's sampling and testing program on Granular A gradation the following conclusions may be drawn:

(a) The producers technician carried out random sampling of the aggregates at the required time and frequency from the stopped conveyor belt during production.

(b) Gradation testing was performed in the laboratory at Walker Bros. Quarry, Thorold, Ontario, according to M.T.C. methods and procedures. Excellent laboratory

facilities enabled the Quality Control Technician, to perform the gradation tests conscientiously and accurately.

(c) M.T.C. carried out a full acceptance testing program in accordance with the special provision for Granular A gradation (July 1981) at the time the material was being stockpiled.

(d) Statistical comparison of the producer's and M.T.C. test results proved that both sets of data represented the same population, so that the producer's test results were acceptable.

(e) The analysis also indicated that there was some segregation of the material in the stockpiling process. This segregation did not effect the acceptability of the lots, but resulted in a larger variability of the end product than the variability of the aggregates when they were produced.

8. Acknowledgements

Grateful appreciation is expressed to the staff of Walker Industries and in particular to Mr. John Cowan, Sales Manager, Mr. Ed Lamb, Operations Technician and Mr. Mike Gillap, Quality Control Technician for their participation and co-operation in the Pilot Project.

The co-operation of the M.T.C. staff and in particular Mr. Bill Foltarz, Project Supervisor at the Martindale Road field office was appreciated.

APPENDIX

SPECIAL PROVISION

JULY 1981

GRANULAR A - Item No.....

ACCEPTANCE OF GRANULAR A

Description

The Ministry will determine the acceptability of Granular A gradation and percent crushed particles on a lot-by-lot basis as outlined in this special provision. When either the Granular A gradation or the percent crushed particles is not within the limits specified in this special provision, an adjusted payment will be allowed at the request of the Contractor in lieu of rejection, except where the non-conformance is so great that the material is totally unacceptable.

References

MTC Laboratory Testing Manual.

Definitions

LOT	- a specific quantity of material normally from a single source, or a specific amount of construction assumed to be produced by the same process.
SUBLOT	- approximately equal divisions or portions of a lot.
MEAN	- the arithmetic average of a set of data.
RANGE	- the difference between the largest and smallest measurement in a set of data.
RANDOM SAMPLE	- a sample chosen in such a manner that each portion in the sublot has an equal probability of being selected.
ROAD SAMPLE	- samples for which the test results are not available until after the material is placed in the work.
RANDOM NUMBER TABLE	- a set of numbers generated by chance.
CONTROL CHART	- a graphical method of presenting test data.

Lot Size

Where the daily production rate is 2 000 tonnes or more, the lot size shall be not greater than 4 000 tonnes or one day's production, whichever is the less.

Where the daily production rate is less than 2 000 tonnes, the lot size shall be determined by the Engineer and may be more than one day's production, but not more than 2 000 tonnes.

The lot size may be increased if the previous four lots have met the specification requirements, but shall not be greater than 10 000 tonnes or one week's production, whichever is the less.

In the event that operational conditions cause work to be interrupted before the lot has been completed, the Engineer may determine the acceptability of the uncompleted lot on the basis of the test results of the uncompleted lot only.

Where it is necessary to designate the quantity of material in a lot or part of a lot, for the purpose of payment adjustment, the Engineer's estimate of this quantity shall be used.

Sampling

The Ministry will perform all necessary sampling and testing for acceptance purposes.

Each lot shall consist of four sublots, and one random sample shall be taken from each.

Sampling may be carried out at the source during production, from existing stockpiles, or by road sampling.

Samples taken during production will be taken as the material is crushed and stockpiled.

Samples may be taken from existing stockpiles containing 4 000 tonnes of material or less. Where he is satisfied that equivalent accessibility for sampling is provided, the Engineer may permit larger stockpiles to be sampled after subdividing or otherwise reworking by and at the expense of the Contractor.

Road samples will be used when the Engineer decides that sampling at the source or from existing stockpiles will not ensure that the material sampled is representative of that to be delivered to the job site.

Where sampling at the source is used, samples will be taken at random times related to the amount of material being produced. Where stockpile or road sampling is used, samples will be taken from tonnages selected at random or from areas selected at random. Regardless of the method of sampling followed, tables of random numbers will be used.

The Contractor will be advised, in writing, prior to the use of road sampling. Samples taken from material already placed on the road, other than retest samples, shall be taken prior to compaction, for which the Contractor shall provide reasonable opportunity.

Testing

Gradation testing of the samples will be performed by the Ministry as described in MTC Laboratory Testing Manual, Test LS-602 "Method of Test for Sieve Analysis of Fine and Coarse Aggregates".

Gradation test results will be computed for each sieve designated in Table 1.

Testing for percent crushed particles will be performed by the Ministry as described in MTC Laboratory Testing Manual, Test LS-607, "Method of Test for Determination of Percent Crushed Particles in Processed Coarse Aggregate".

Tests from production, stockpile, and road samples will not be mixed in considering the acceptance of any particular lot, except where necessary when retesting.

Individual gradation and percent crushed particles test results for sublots, lot means, and ranges will be recorded on control charts by the Ministry.

Specification Requirements

(i) Gradation

(a) Lots (Completed)

A lot of Granular A will be deemed to meet the specification requirements for gradation if the mean of the four test results of the lot is within the gradation limits specified in Table 1 and the range of the test results of the lot is equal to or less than the maximum acceptable range in Table 1.

(b) Uncompleted Lots

In the event that the Engineer decides that acceptance will be determined on the basis of an uncompleted lot, the uncompleted lot shall be deemed to meet the specification requirements for gradation if the mean of the results is within the gradation limits in Table 11 for one, two or three sublots and, in the case of two or three sublots, if the range of the tests is within the maximum range given in Table 1.

TABLE 1

GRADATION REQUIREMENTS - FOUR SUBLOTS

Ministry Sieve Designation	% Passing by Mass Four Sublots	Maximum Acceptable Range %
37.5* mm	100	0
19.0 mm	70 - 100	20
9.5 mm	50 - 73	18
4.75 mm	35 - 55	16
1.18 mm	15 - 40	18
300 µm	5 - 22	12
75 µm	2 - 8	5
	2 - 10**	5**

* Where the contract requires the maximum particle size to be 22.4 mm, the percentage passing that sieve shall be 97-100 and the maximum acceptable range shall be 3%.

** Where the Granular A is obtained from a quarry source.

TABLE 11

GRADATION REQUIREMENTS - LESS THAN FOUR SUBLOTS

Ministry Sieve Designation	% Passing by Mass		
	One Sublot	Two Sublots	Three Sublots
37.5* mm	100	100	100
19.0 mm	60-100	63-100	67-100
9.5 mm	41- 82	44- 79	47- 76
4.75 mm	27- 63	30- 60	33- 57
1.18 mm	6- 49	9- 46	12- 43
300 µm	0- 28	1- 26	3- 24
75 µm	0- 11	1- 9	1.5-8.5
	0- 13**	1- 11**	1.5-10.5**

* Where the contract requires the maximum particle size to be 22.4 mm, the limits for that sieve for one, two and three sublots shall be 95.5-100, 96-100 and 96.5-100 respectively.

** Where the Granular A is obtained from a quarry source.

(ii) Percent Crushed Particles

A lot or uncompleted lot of Granular A shall be deemed to meet the specification requirements for percent crushed particles if the mean of the test results is equal to or greater than the applicable value shown in Table 111, and, where there is more than one sublot, no individual sublot has a test result less than 45%.

TABLE 111

No. of Sublots	Percent Crushed Particles
One	45
Two	47
Three	49
Completed Lot (Four)	50
Retested Lot	52

(iii) Visual Examination

Notwithstanding the above testing of the Granular A, any load which is observed visually by the Inspector to be outside the specification requirements shall be rejected. Should the Contractor require, this rejection shall be confirmed by taking two random samples from the load and applying the requirements for an uncompleted lot with two sublots. Where this testing confirms that the load qualifies for rejection under Section (iii) of the Basis of Payment, the Contractor shall be charged the cost of retesting at half the rate shown in Section (iv), Retesting. In all other cases the cost of sampling and testing shall be borne by the Ministry and the load shall be decisioned as part of the lot.

Basis of Payment

(i) Payment at the Contract Price

Payment for lots and uncompleted lots which meet the specification requirements shall be made at the contract price for Granular A.

(ii) Adjusted Payment

Payment for lots or uncompleted lots which do not meet the specification requirements but which are not subject to rejection under (iii) following, shall be adjusted as follows:

(a) Gradation

If the Contractor chooses to use a lot of Granular A which does not meet the specification requirements for gradation, or where such a lot cannot be totally excluded from the work, payment for that lot shall be made at a price equal to the contract price for Granular A less a percentage equal to the sum of the adjustment points determined on the following basis: For each 0.1% that the mean gradation falls outside the applicable limits for each sieve, adjustment points shall be applied according to Table IV.

TABLE IV

Ministry Sieve Designation	Adjustment Points per 0.1% Deviation from Specification Limits
37.5* mm	0.1
19.0 mm	0.1
9.5 mm	0.1
4.75 mm	0.5
1.18 mm	0.1
300 µm	0.1
75 µm	1.0

* Where the contract requires the maximum particle size to be 22.4 mm, the adjustment for the 37.5 mm sieve shall apply to the 22.4 mm sieve.

For each 0.1% that the range exceeds the maximum acceptable range for each sieve, shown in Table 1, 0.1 adjustment points shall be applied.

(b) Percent Crushed Particles

If the Contractor chooses to use a lot of Granular A which does not meet the specification requirements for percent crushed particles, or where such a lot cannot be totally excluded from the work, payment for that lot shall be made at a price equal to the lesser of:

- the contract price for Granular A less 5% for each percent that the lot average falls below the applicable limits shown in Table 111, or

- the contract price for Granular A less 5% for each percent that any one sublot falls below 45% (47% in the case of a retest).

(c) Gradation and Percent Crushed Particles

If the contractor chooses to use a lot of Granular A which does not meet the specification requirements for gradation, and which also does not meeet the specification requirements for percent crushed particles, or where such a lot cannot be totally excluded from the work, payment for that lot shall be made at a price equal to the contract price for Granular A less the sum of the percentages prescribed in (a) and (b) above.

(iii) Rejection

Lots or uncompleted lots which are either

- subject to a price adjustment of more than 25% of the contract price in respect of gradation only, or

- subject to a price adjustment of more than 25% of the contract unit price in respect of percent crushed particles only,

shall be rejected and shall not be incorporated in the work, or, where already incorporated shall be removed from the work.

(iv) Retesting

Upon receipt of the test results on any lot the Contractor may require in writing that the lot be retested, either for gradation or for percent crushed particles, or for both.

Where such notice is given, the Ministry shall carry out the retesting by taking an additional random sample from each sublot and testing it for gradation, percent crushed particles, or both, as designated by the Contractor.

The lot shall then be re-decisioned for payment or rejection as in (i), (ii), and (iii) above, except that:

- the average of the two test results on each sublot shall be used in place of the single test result, and

- the gradation limits shown in Table V shall be used in place of those shown in Table 1.

No lot shall be retested more than once.

TABLE V

GRADATION REQUIREMENTS - FOUR SUBLOTS

TWO SAMPLES PER SUBLOT

Ministry Sieve Designation	% Passing by Mass
37.5* mm	100
19.0 mm	75 - 95
9.5 mm	52 - 71
4.75 mm	37 - 53
1.18 mm	17 - 38
300 µm	7 - 20
75 µm	3 - 7
	3 - 9**

* Where the contract requires the maximum particle size to be 22.4 mm, the percentage passing that sieve shall be 97.5-100.

** Where the Granular A is obtained from a quarry source.

Where the retesting causes a lot which had been subject to rejection or to acceptance at an adjusted price, to be accepted at the contract price, the cost of the additional sampling and testing shall be borne by the Ministry.

In all other cases the Contractor shall be charged the cost of retesting as follows:

Gradation only	$200 per lot
Percent Crushed Particles only	$ 80 per lot
Gradation and Percent Crushed Particles	$280 per lot

(v) Delay to the Work

All costs arising from any delay whatsoever to the work which may be occasioned by the procedures required herein shall be deemed to be included in the contract price for this item.